NBSIR 79-1706

CSA Weatherization Demonstration Project Plan

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National Engineering Laboratory
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U.S. DEPARTMENT OF COMMERCE, Juanita M. Kreps, *Secretary*

Jordan J. Baruch, *Assistant Secretary for Science and Technology*

NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director*

TABLE OF CONTENTS

LIST OF FIGURES AND TABLES

CONVERSION TO SI UNITS

In view of the present accepted practice in this technological area, U.S. customary units have been used throughout this report. It should be noted that the United States is a signatory to the General Conference on Weights and Measures which gave official status to the International Systems of Units (SI)--the modern metric system--in 1960.

Readers interested in making use of the coherent SI units will find conversion factors in ASTM E380-76[r], "Standard for Metric Practice," and ANSI/ASTM E621-78, "Standard Practice for the Use of Metric (SI) Units in Building Design and Construction," available from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, PA 19103.

Conversion factors for units used in this paper are listed below. The use of an asterisk (*) behind a unit denotes an exact conversion.

Length
    1 in   =   25.4 millimeters (mm)*
    1 ft   =   0.3048 meter (m)*

Area
    1 ft^2 =   0.0929 square meter (m^2)

Volume
    1 ft^3 =   0.0283 cubic meter (m^3)
    1 gal =   3.785 liters (L)

Energy
    1 Btu (Int. Table) = 1.055 kilojoules (kJ)
    1 therm (100,000 Btu) = 105.5 megajoules (MJ)

Energy Flow Rates
    1 Btu/($ft^2 \cdot$hr$\cdot$°F) = 5.678 watts per square meter kelvin
                    (W/$m^2 \cdot$K)--U-value
    1 Btu/($ft^2 \cdot$yr) = 27.63 kilowatts per square meter (kW/m^2)
    1 Btu/(ft$\cdot$yr) = 783 watts per meter (W/m)

Energy Flow Resistance
    1 °F$\cdot$h$\cdot$$ft^2$/Btu = 0.176 square meter kelvin per watt ($m^2 \cdot$K/W)--
                    R-value

Volume Rate of Flow
    1 ft^3/h = 0.0079 liter per second (L/s)

Temperature Interval
    1°F = 0.556 degree Celsius (°C) or kelvin (K)

Equivalent Temperature Value

$$°F = 0.556°C + 32$$

Accumulated Temperature Deficiency--Degree Day

1 DD (at [base temp.] °F) = 0.556 DD (at [equivalent base temp.] °C)

ABSTRACT

This report comprises the plan of a research and demonstration effort
to determine the fraction of energy that may be saved by installing
weatherization retrofits in poor peoples' homes throughout the
United States. Two broad groups of weatherization retrofits are
considered for application in each dwelling: 1) "architectural,"
those affecting the building shell; and 2) "mechanical," those
affecting space heating and service hot water systems. The optimum
combination of weatherization options is defined as that set of
retrofits which maximizes net savings (the difference between savings
in fuel usage and the cost of the retrofits) over 20 years for a
particular house and climatic environment. The retrofits will be
selected through present-value benefit/cost analysis. The savings
will be established through analysis of utility billings and fuel
delivery records before and after weatherization. The report presents
the background of the demonstration, the research tasks associated
with the demonstration, a description of the diagnostic tests to be
used, the rationale for economic decisions, the tests for evaluating
mechanical systems, and the calculation methods used in selecting
architectural options.

Key words: Community Services Administration; heating balance
           point analysis; low-income residences; marginal cost/
           benefit analysis in weatherization; optimum weatherization
   retrofit combinations; thermal analysis of residences

1. INTRODUCTION

The Community Services Administration (CSA), in order to better evaluate
how it might best help low-income families cope with the high and
increasing costs of energy, wants to know the maximum dollars that
can be saved through weatherization of the homes occupied by the poor
in all parts of the United States. Information about optimal weatheri-
zation of such homes and the energy-saving results will allow CSA to:
1) more effectively distribute Federal funds across the country,
2) avoid the extra expenses incurred by going back to houses for addi-
tional weatherization, 3) predict the savings in fuel and money that
can be achieved by the weatherization program, and 4) consider ini-
tiating a loan program as a source of additional money for weateriza-
tion. Because wide variation has been observed between calculated and
field measured data on possible energy savings, CSA is conducting a
national demonstration and research project to determine energy savings
through cost effective weatherization of low-income homes. This demon-
stration, addresses three areas of residential energy use: 1 - the
building space heating load; 2 - the operation of the building space
heating system; and 3 - the operation of the service hot water system.

The National Bureau of Standards (NBS) has designed the experimental
plan and will provide technical support to this demonstration. This
support will include selecting demonstration sites, individual homes
and weatherization options; planning and supervising the collection of
various kinds of data from the demonstration homes before and after
weatherization; and analyzing the data and evaluating the homes in
relation to that data. Utility bills and meter readings for the indi-
vidual homes will be the basic measure used to evaluate energy savings.
Although the project will provide CSA with the best data available
on energy savings through applying energy conservation to existing
buildings, its main contribution may be the methods it presents for
monitoring and evaluating weatherized houses. With these methods CSA
and other agencies could develop the capability to improve the data
collected by this project and evaluate new energy conserving techniques
as they are proposed.

In FY 78, CSA/NBS field tested this experimental plan in one of the
16 (see Figure 1) site cities -- Portland, Maine. In FY79, CSA/NBS
intend to evaluate the cost effectiveness of weatherization in Portland
and, using the experience gained in Portland, to weatherize homes and
evaluate the cost effectiveness of weatherization in the other fifteen
cities.

Two questions will be answered by this demonstration. First, what is
the typical energy consumption, in Btu's per square foot, of unweath-
erized and optimally weatherized homes in various climates? Second,
what are the savings, expressed as a percent, that can be expected
from optimally weatherizing low-income homes? The answer to the first
question will be very useful in estimating the minimum energy use achiev-
able in a given type of dwelling in a given climate zone using a cost
effective package of architecture and mechanical options. The answer

1

SELECTED SITES FOR DEMONSTRATION

PORTLAND (7493)

EASTON (5827)

WASHINGTON D.C. (4211)

CHARLESTON (1904)

MIAMI (206)

ATLANTA (3095)

NEW ORLEANS (1465)

CHICAGO (6127)

ST. LOUIS (4750)

MINNEAPOLIS (8310)

FARGO (9271)

COLORADO SPRINGS (6473)

ALBUQUERQUE (4292)

TACOMA (5185)

OAKLAND (2909)

LOS ANGELES (1819)

LEGEND:

(0000) - DEGREE DAYS

FROM NATION CLIMATIC CENTER'S
1941-70 HEATING DEGREE DAY
YEARLY NORMALS

FIGURE 1

2
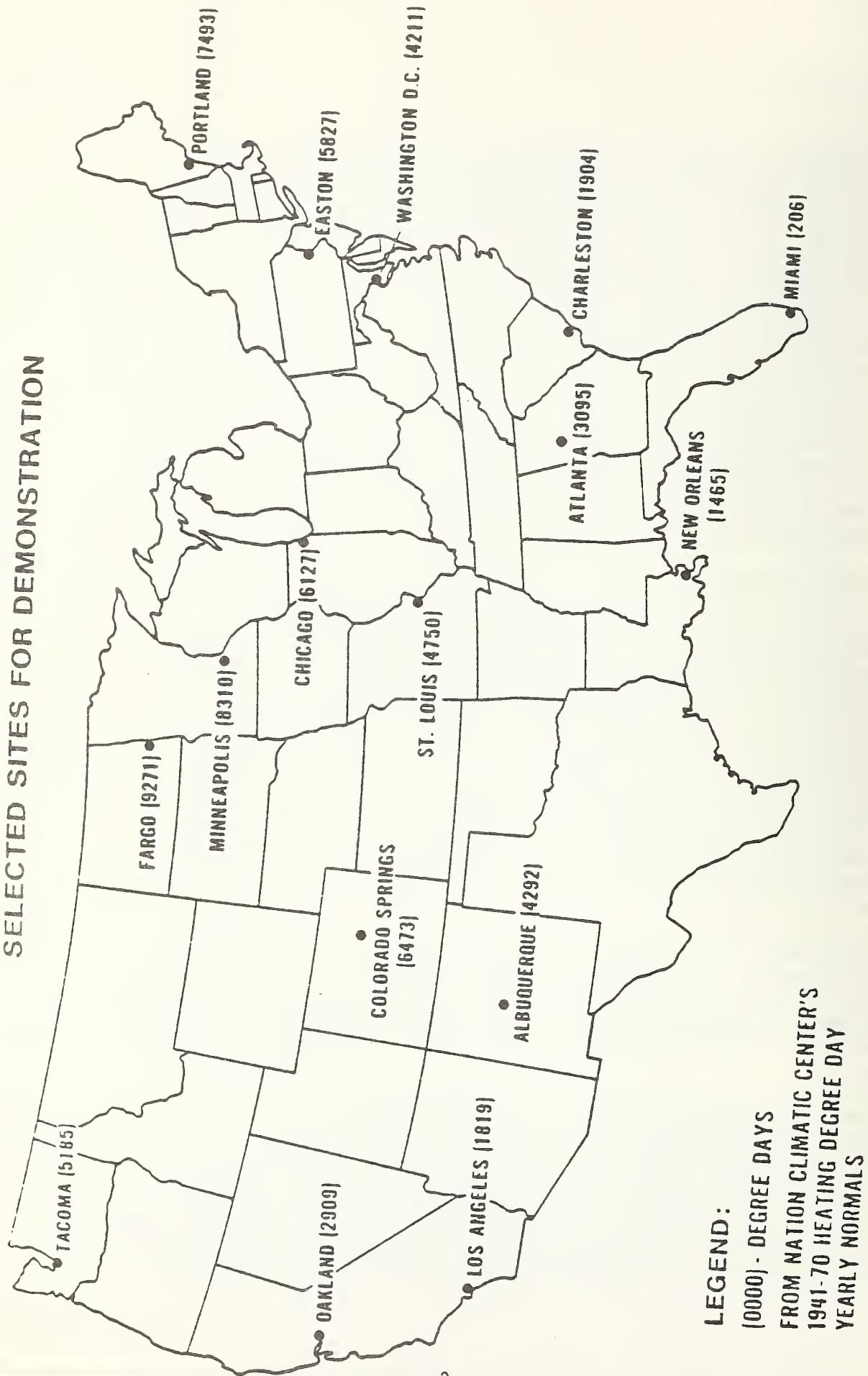
to the second will be useful for understanding the range of expected savings that can be achieved by installing a cost effective package of architectural and mechanical options, independent of behavioral and other variables.

Energy consumption after weatherization will be measured by reading fuel meters. Energy consumption for two years before weatherization will be obtained from existing utility records. By comparing energy consumption records before and after weatherization, as well as across houses, reliable estimates of the change in energy consumption as a result of weatherization will be obtained. Variation across houses in the same climate will be initially explained through differences in floor area, balance point, orientation, and occupant activities. If these factors are unable to explain variations in energy consumption, more detailed studies on infiltration, amount of glass area, temperature distribution, heating system operations, and conductive heat losses will be conducted.

2. DEMONSTRATION DESIGN

The NBS/CSA demonstration will install "optimum" weatherization in several houses in each climate zone and measure the energy consumption of those houses before and after weatherization. The selection of sites, houses, and weatherization options, and the analysis data will be done by NBS. The installation of the options and the collection of data will be done by local community action agencies.

The houses to be employed for the demonstration will be selected from houses proposed by local community action agencies (CAA). The houses proposed are to meet a broad set of criteria. (The criteria are listed on pp. 5 and 7.) In order to select the set of demonstration houses, NBS will evaluate the characteristics of each house and the accuracy of the submitted fuel data. The fuel use records will be analyzed by plotting fuel consumption against degree days and finding the best-fit regression line by letting the heating balance point parameter "float." (The balance point analysis is discussed on pp. 9-10.)

Once the houses have been selected by NBS, the local community action agencies will be sent a list of the demonstration houses and instructed to find a local heating contractor to install meters and thermometers and to perform mechanical tests on the heating and hot water systems. After installation of the instruments, reading of fuel meters and thermometers will start as soon as possible.

When the results of this testing have been received at NBS, architectural and mechanical options will be selected. (The options being considered in the demonstration are listed on pp. 8 and 9.) The architectural options will be selected on a house-by-house basis, depending on the type of fuel used for heating the house and the annual degree days (computed on a base of 65°F) for that climate.

Optimization of weatherization will be achieved through the use of marginal analysis, which examines the incremental savings and costs of each level of implementation of an option in order to determine the level that will result in the greatest net savings (savings minus cost). The length of the study period over which the marginal analysis will be conducted is 20 years. In order to insure that a weatherization investment will not place undue financial burdens on the homeowner, a payback constraint is imposed. Eleven years was selected for the payback period, since CSA hopes to institute a loan program and this time period is consistent with the term of usual renovation loans. It is important to point out that the 11-year payback constraint is applied only to the aggregate level of weatherization for each option, not to each increment of that option. In this sense the payback constraint can be thought of as being directly analogous to a physical barrier. (For example, R19 might be the theoretical optimal level of wall insulation over 20 years, but if only R11 will pay for itself in 11 years, only R11 would be installed.)

The mechanical options will also be selected on a house-by-house basis. Based on an evaluation of the mechanical systems tests, a list of options will be made for each house, with the options ranked on the basis of generally accepted savings associated with each option. Using this list, a combination of options will be selected which will raise the seasonal efficiency of the heating system from the measured value to 65 percent for oil, 70 percent for gas, and 100 percent for electricity. The selection of mechanical options differs from the selection of the architectural options in that each mechanical option constitutes an increment. Thus each mechanical option is assessed incrementally, using a 20-year life cycle. The whole set of options for the mechanical system of a house is then tested against the 11-year payback constraint.

Once the options have been selected by by NBS, they will be installed by the local CAA, using contracted and CETA*labor. It will be the local CAA's responsibility, with guidance from CSA/NBS, to make sure that the options are installed using appropriate materials and methods of installation. Local CAA's will also be responsible for inspecting each house to identify and remedy any fire or health hazards, or potential code violations, before any options are installed.

Cost data will be collected by local CAA's while the options are being installed. (This phase of the demonstration is discussed on pp. 27-34.) Various other types of data on the building and its occupants will also be collected by local CAA's (these are described on pp. 34 to 36.) When all of the data have been received, NBS will calculate the savings achieved in the demonstration, and make recommendations for further

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* The Comprehensive Employment and Training Act provides Federal funding to support various types of public-service jobs (for formerly unemployed workers). Labor underwritten with these funds carries out much of the weatherization work organized by CAAs.

testing if required to explain variations in the results. When such tests have been performed and data collected from them, the preliminary findings of the demonstration will be re-evaluated, and recommendations made to CSA for optimizing weatherization throughout the continental United States.

3. SELECTION OF DEMONSTRATION STIES

The sites for the demonstration were selected by NBS based on climate. This is considered the major variable in residence energy consumption, so it was removed as a variable from the demonstration by proposing demonstrations in a variety of climates. The climates selected represent all of the important inhabited climates of the United States. They were selected on the basis of the climatic parameters which are important to building energy consumption, including temperature, humidity, sunlight and wind. A map which divides the country into 11 zones of 1000 heating degree day widths was used as a base map. Subdivisions within the degree day zones were then made, based on classification systems which consider other climatic variables (Ref 4). The availability of climate data was also a consideration. From this study, the cities shown in Figure 2 (p. 6) were proposed to Regional CSA offices as sites for the demonstration.

Some of these cities were not able to meet program requirements of the demonstration, such as being able to install the options in a short period of time. As a result, the 16 Cities in Figure 1 (p. 2) were finally selected.

4. ACQUISITION OF DESCRIPTIVE DATA ON DEMONSTRATION HOMES

A local CAA in each of the 16 cities selected as a site was requested to submit to NBS data on 27 to 50 homes which met the following criteria and from which demonstration homes could be selected by NBS:

　　1. All homes should be simple rectangular or square homes. Two-thirds of them could have unheated porches or spaces attached to them.

　　2. The homes should comprise an even distribution of:

　　　　a) Building Types: one-story detached, two-story detached, and two or three-story attached.

　　　　b) Construction Types: wood, 8" masonry or adobe, and masonry veneer.

　　　　c) Heating Systems: central hot water, central hot air and space heaters.

PROPOSED SITES FOR DEMONSTRATION
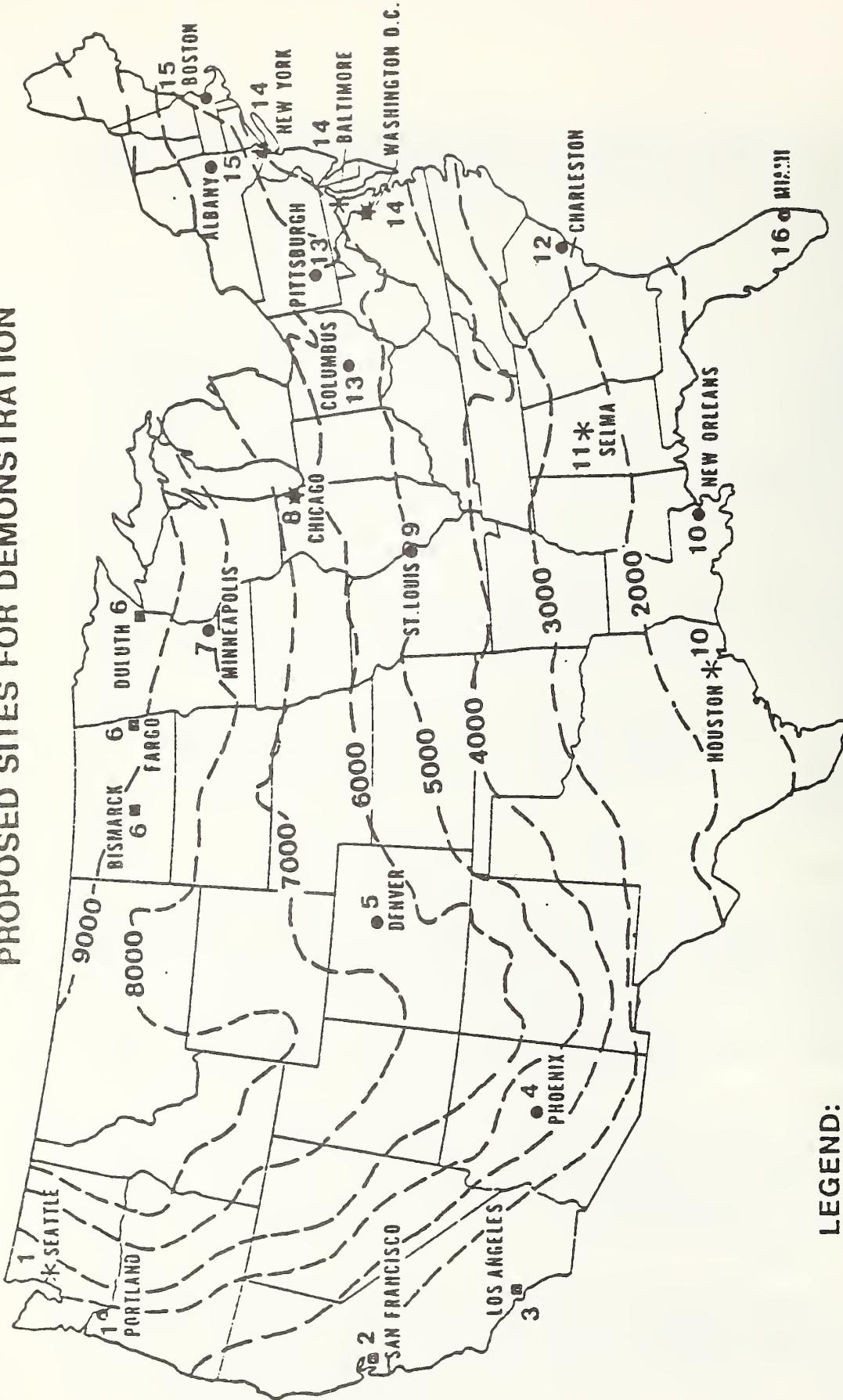
LEGEND:

● AIA CLIMATIC SUMMARY AVAILABLE.

✱ USWB CLIMATIC GUIDE OR HANDBOOK AVAILABLE.

◼ OTHER RECOMMENDED SITES.

FIGURE 2

6

3. The homes should represent a variety of periods in history. At least two should have been built before World War I, two between World War I and World War II and two after World War II.

4. All homes should be in reasonable condition, i.e., roof water-proof, doors in place, mechanical systems in working condition, etc.

5. All homes should have an accurate way of measuring fuel consumption on a weekly basis.

6. All homes should not have had any major changes made to the shell or mechanical system since April 1975.

7. All homes should have had the same occupant since April 1975.

8. The homes should include a variety of occupants and household characteristics that are typical of the locale, including variations in size of family, age of occupants, ethnic origin of household members, etc.

Sample buildings of any types not covered by the specific criteria were also requested. The following information was requested for each house:

1. A complete and accurately prepared Building Weatherization Plan (CSA Form No. 116 RQ 305).

2. Certification that the household is program eligible.

3. Photographs of all sides of the building.

4. Utility bills (water, gas, oil, electricity, wood, etc.) since April 1975 and authorization to obtain access to future records of energy consumption.

5. Authorization from occupants to make extensive measurements and administer questionnaires.

6. The location of the house shown on a typical gas station road map.

7. A summary on one sheet of how the houses met the various requirements of the demonstration.

The local CAA's at the demonstration sites were also asked to submit fuel bills typical of their area, and to assure NBS and CSA that they could install the weatherization options within six weeks after they were given the go-ahead.

5. IDENTIFICATION OF ARCHITECTURAL AND MECHANICAL OPTIONS

Based on experience in Chicago with Multi-family Weatherization (Ref. 2) and a search of the literature for viable weatherization options for low-income housing, the following options were chosen by NBS and approved by CSA for consideration in the demonstration.

5.1 ARCHITECTURAL OPTIONS

5.1.1 Infiltration

1. Replace broken glass
2. Reset glazing in windows
3. Replace threshold
4. Seal structural cracks
5. Weatherstrip windows
6. Caulk windows
7. Weatherstrip doors
8. Caulk doors
9. Weatherstrip attic hatch

5.1.2 Windows

10. Install storm windows
11. Install insulating drapes (R = 1.14)
12. Install insulating shutters (R = 7.8)
13. Install low emissivity films
14. Install triple glazing

5.1.3 Doors

15. Install storm door
16. Install second wood door (R = 2.18)
17. Replace exterior door with insulating door (R = 6)

5.1.4 Insulation

18. Install attic insulation (R = 11, 19, 30, 38)
19. Install wall insulation (R = 11+ vapor barrier where possible)
20. Install first floor insulation (R = 19, 30)
21. Install carpet on floor
22. Install basement wall insulation (R = 7)
23. Install perimeter slab insulation

5.2 MECHANICAL SYSTEMS OPTIONS

5.2.1 Furnace

1. Install flue or vent damper
2. Install flue or vent restrictor

3. Install electronic ignition
4. Install two-stage gas valve
5. Derate furnace - reduce orifice or nozzle size and install diverter
6. Replace burner
7. Replace furnace (change distribution system when required)

5.2.2 Distribution & Control System

8. Insulate ducts and pipes
9. Install reflectors behind radiators
10. Install night setback thermostat
11. Relocate thermostat

5.2.3 Hot Water Heater

12. Insulate water heater
13. Replace water heater
14. Reduce temperature setting on water heater
15. Install flow restrictor on shower
16. Install timer on electric water heaters

6. CALCULATION OF HEATING BALANCE POINT OF EACH HOUSE

The heating balance point (average outside temperature in °F at which heating system comes on to maintain the interior thermostat setting) and the K-factor (rate at which the house consumes energy in Btu/degree day) will be determined by NBS for each house in the demonstration, before and after weatherization, by applying standard correlation and regression techniques to fuel consumption and weather data. Given this data, the set of measures of fuel consumption can be plotted against local degree days for the respective time periods. Different balance points result in different degree day totals for any periods having days with temperatures below the balance point. By finding the balance point that produces the best "fit" of a straight line to a fuel use temperature data plot, we have a very good measure of space heating fuel consumption for a house. (Ref. 3.) We can also most accurately calculate the expected fuel consumption of the house for other time periods, from the temperature data for such time periods, provided the other variables associated with energy consumption, such as construction and thermostat setting, remain constant. Base temperatures from 45°F to 85°F will be evaluated in this project, to determine which gives the best fit. Figure 3 (p. 10) is a sample computer printout of a balance point calculation. In this figure, T_o is the balance point of the house, B_1 is the slope or K-factor of the best fit line (least squares line), and B_o is the base load per degree day or that portion of the fuel consumption which can not be attributed to weather variations (including, in the sample case, the heating of service hot water through a "tankless coil" in the furnace).

WEATHERIZATION DEMONSTRATION
PORTLAND, MAINE

POR 02
X MEAN = 18.87
X VAR. = 13.62
Y MEAN = 5.37
Y VAR. = 2.08
T_0 = 56.00
B_0 = 1.14
B_1 = 0.212
R**2 = 0.9895
STD. ERROR = 0.30
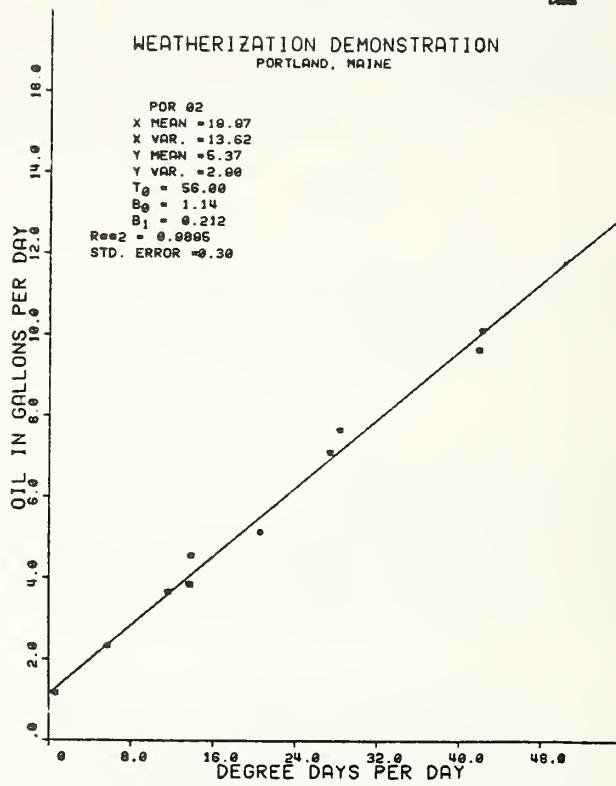
Sample Balance Point Graph

FIGURE 3

By making these same balance point calculations before and after optimum
weatherization, and normalizing these results for differences in degree
days between the two sets of data, NBS will be able to calculate the
energy savings achieved through optimum weatherization.

7.   SELECTION OF DEMONSTRATION HOMES

From the list of homes proposed by the local CAA's, NBS will select
the demonstration sample houses. Houses for the demonstration will be
selected, first of all, on the accuracy of their submitted fuel data;
secondly, on their representation of a broad range of the variables
which affect energy consumption; and thirdly, on having been occupied
by the same family since April, 1975. The accuracy of the fuel data
will be examined using the regression ("best fit") calculations pre-
viously described. The broad range of variables, other than climate,
which affect energy consumption have been identified as: building size,
construction type, building type, building shape, building age, percent
of wall area in glass, orientation, and occupant behavior.

10

Some of these variables are expected to vary naturally across a sample of 27 to 50 homes at each site, other variables will be restricted, while still other variables will require an effort to insure that a natural range of variation for low-income housing is included in the sample. Orientation, size, glass area, and occupant behavior are variables which are expected to show sufficient natural variation. Building shape is a variable which will be limited to simple rectangular buildings with unheated porches or appendages. The distribution of building types, construction types, age and heating system types are variables which will have to be controlled. In order to control this distribution, local CSA groups will be asked for a sample of five houses of each building-type construction-type combination, two houses of each age category, and an even distribution of heating systems that are typical of each site. The building types requested will be one-story detached, two-story detached, and two and three-story attached. The construction types requested will be frame, masonry or adobe, and brick veneer. The age categories requested will be pre-World War I, World War I to World War II and postWorld War II. The heating systems sampled will be forced air, gravity air, space heaters, hot water and steam.

8. INSTALLATION OF UTILITY METERS AND THERMOMETERS

Meters, thermometers and other measuring devices will have to be installed in the demonstration homes by CSA according to NBS specifications. These will be installed as early as possible, so that detailed data both before and after weatherization can be collected.

The type of meters installed will depend on the type of fuel used for space heating and domestic hot water in each house. All furnaces or space heaters will have a run time meter and a cycle counter installed, in order to determine the total amount of time the furnace or space heater is operating and the number of times it cycles on and off. On gas and electric furnaces or space heaters, an appropriate utility meter will be installed in order to read the total amount of energy consumed for space heating. In houses with propane or bottled gas, a gas meter will be installed between the gas tank and the furnace.

It should be noted that for bottled gas and oil, the data on the past two years usage will be limited to measurements made by delivery truck meters when the storage tanks were filled completely, while measurements of natural gas and electricity consumption will be available from monthly or bimonthly readings of the utility meters. Data of both types should continue to be available during the demonstration.

In order to get accurate information on indoor temperatures and humidity, additional measurements will be made. Dry bulb thermometers should be installed near the center of the house on each floor including the basement. A sling psychrometer (wet and dry bulb thermometers) will be used

11

by the local CSA coordinator to determine the humidity in the house when making weekly site visits.

In order to assess the effectiveness of the weatherization options related to reducing the energy required for water heating, a gas or electric meter will be installed on the water heater and a water meter will be installed on the cold water supply to the heater. Requirements for the installation of these meters are listed in Appendix A.

9. SELECTION OF MECHANICAL OPTIONS

The types of mechanical options which are being considered by NBS for installation in each weatherized house can be classified as those that affect a) the control system, b) the efficiency of the furnace, c) the efficiency of the heat distribution system and d) the efficiency of the domestic hot water service. The mechanical options intrinsically differ from the architectural options. First, the cost of installing the option is usually load independent, while the savings produced are dependent on the dwelling heating load or the hot water consumption. Secondly, the amount of savings that can be obtained from most mechanical options depends on the existing condition of the mechanical system. Therefore, it is not possible for NBS to predict the savings that would result from installing various mechanical options unless the present efficiency of the heating system is known.

9.1 MECHANICAL OPTIONS

Before mechanical options are selected, the heating system in each house is tested and cleaned (as described in Appendix B). At this time the furnace is tuned, the distribution system balanced, non-functioning traps, flow valves and air valves replaced, and a barometric damper is installed as required. The mechanical options listed on pages 8,9 are beyond this basic service, and will be selectively implemented where economically justified, contingent also on their being in compliance with state and/or local codes or a code variance, as determined by local CAA's.

In order to simplify the selection process, the architectural options and the mechanical options have been separated. This is acceptable as long as optimum weatherization is defined as that combination of architectural and mechanical options which results in the greatest net dollar savings over the life cycle (i.e., which produces a marginal benefit/marginal cost ratio equal to one). The two types of options can initially be dealt with separately, by assuming a conservative overall mechanical efficiency of 65% for oil, 70% for gas, 100% for electricity in doing the calculations to select architectural options, and assuming a 50% reduction in building load when selecting the mechanical options. However, in the analysis for final option selection, actual estimates of equipment efficiency and heating load will be used.

Figure 4 presents a worksheet used for displaying the costs and savings associated with various options. The method of calculating the percentage of savings associated with each option is presented in Appendix C.

Some of the mechanical options may not have a 20-year physical life. In order to make the present costs of all the options compatible with an assumption of a 20-year life, the first costs of the options must be adjusted to reflect the present value of costs of any replacements needed within a 20-year period according to the values listed in Table 1. Options not listed in Table 1 are not expected to require replacement before the 21st year. The replacement assumptions listed in Table 1 will be included in the present cost estimates, using a 6% real discount rate. A zero real price increase in the cost of the mechanical options will be assumed.

Based on the equations in Appendix C and the data on replacement frequencies in Table 1, savings and costs associated with each mechanical option are calculated. The approach used in selecting the mechanical options requires that each option be able to pay for itself in 20 years (recall that the mechanical options are treated as increments) and the complete set of mechanical options pay for itself in 11 years.

MECHANICAL OPTION SELECTION WORKSHEET

COST/SAVINGS

House Number	Flue or Vent Damper	Flue or Vent Restrictor	Electronic Ignition	Two Stage Gas Valve	Derate Furnace	Replace Burner	Replace Furnace	Insulate Ducts & Pipes	Radiator Reflector	Night Setback Thermostat	Relocate Thermostat	Insulate Water Heater	Replace Water Heater	Reduce Temp Water Heater	Shower Flow Restrictor	Timer on Water Heater
1	/	/	/	/												
2	/	/	/													
3	/	/														
4																
5																
6																
7																
8																
9																
10																

FIGURE 4

TABLE 1

ESTIMATES OF THE FREQUENCY OF REPLACEMENT OF SEVERAL
MECHANICAL OPTIONS TO ACHIEVE A 20-YEAR PHYSICAL LIFE

Options Not Having 20-Year Life	Replacement Estimate
Flue or Vent Damper	Replace Full Cost with Furnace
Flue or Vent Restrictor	Replace with Furance
Electronic Ignition	Replace with Furnace
Two Stage Gas Valve	Replace at End of 15th Year
Gas Furnace	Replace at End of 15th Year
Oil Furnace	Replace at End of 10th Year
Electric Warm Air Furance	Replace at End of 15th Year
Water Heater	Replace at End of 10th Year
Water Heater Timer	Replace with Heater
Water Heater Insulation	Replace with Heater
Shower Flow Restrictor	Replace at End of 10th Year
Burner	Replace with Furnace

9.2   SELECTION OF HEATING SYSTEM-RELATED OPTIONS

In order to decide what heating system options are to be installed in a
given house, the tests will be performed and the efficiency of the exist-
ing system will be determined. A local heating contractor will have to
be approved by NBS and hired to perform the tests. Each option that can
be added to the existing system is then assigned a percentage efficiency
improvement value (EIV) based on the efficiency of the existing system.
The efficiency improvement value is multiplied by the present load of
the building reduced by 50% to allow for architectural retrofit, and the
energy savings determined. These are in turn multiplied by the (present
value) fuel cost over 11 years and compared to the cost of the option.

The resulting list of possible options for each house will be ranked by efficiency improvement values, with the largest EIV first. Working down from the top of the list, options will be selected until the reduced load on which successive options are calculated is no longer large enough to support the cost of that option over 20 years.

Thus the savings, S_j accrued by applying the jth mechanical option are calculated by the relation:

$$S_j = N_j \cdot F_{j-1} \qquad\qquad (1)$$

where $\qquad F_j = F_{j-1} - S_j = (1 - N_j) \, F_{j-1}$

and $\qquad F_o = .5F$

where F is the annual fuel cost for the space heating from pre-weatherization fuel bills and N_j is the percentage of savings attributed to the jth numbered option.

Equations and assumptions to be used for calculating the N_js are shown in Appendix C.

9.3 SELECTION OF WATER HEATER-RELATED MECHANICAL OPTIONS

The water heater is the second largest energy user in a typical residence without air conditioning. In some dwellings in which electricity is used for water heating, the amount of money annually spent to heat water may actually exceed the annual expenditure for space heating. The types of water heaters considered in the demonstration are individually-fueled gas, electric, or oil, storage-type water heaters, and water heaters integral with a gas or oil furnace, either of the tankless coil type or with a small storage tank (aquaboosters). See Appendix B for a description of the tests to be carried out on existing water heaters. Methodologies for selecting water heater options are presented in Appendix C.

10. SELECTION OF ARCHITECTURAL OPTIONS

Since a major objective of the demonstration program is to demonstrate maximum energy savings per dollar spent, NBS will select architectural options by weighing future energy savings against costs, using a life-cycle benefit/cost analysis approach. This approach permits the identification of not only those weatherization options which are cost effective, but also that level of weatherization which is optimal (i.e., will give the greatest return in saved fuel costs for the dollars spent on weatherizing). The basic approach is simple and straightforward. Where various levels of an option are feasible (e.g., insulation), we intend to maximize the net savings over a 20-year life cycle, associated with that type of architectural option. (Net savings is equal to total

savings minus total costs.) The principle is illustrated, for various levels of insulation, in Figure 5.

In the figure, the total cost curve, TC, rises steadily as more units of heat-flow resistance are installed. It can be seen that the first resistance units are the most expensive, due to high start-up costs (set up, labor, equipment, etc.). The total savings curve, TS, first rises quickly and then levels off. This is due to the fact that heat flows are inversely related to the number of units of resistance. Both curves are based on an assumed life cycle, over which both savings and costs are calculated (a 20-year life cycle is being used in the demonstration program analysis). Notice that the two curves intersect at levels R_1 and R_2 of resistance.

OPTIMAL LEVEL OF INVESTMENT
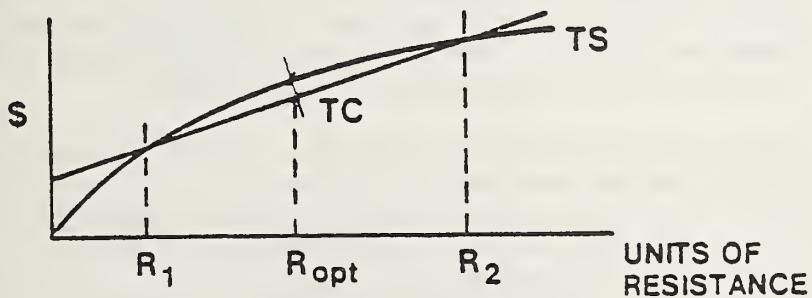
FIGURE 5

At all levels of resistance less than R_1 the total cost of the option exceeds its life-cycle energy savings. Similarly, at all levels of resistance above R_2 total cost exceeds life-cycle energy savings. Therefore, the number of units of resistance to be installed will have to be between R_1 and R_2 if it is to pay for itself over the life cycle. Clearly the number of years it will take for the option to pay for itself will depend on how many resistance units between R_1 and R_2 are installed. Generally speaking, the first units above R_1 will pay for themselves fastest. Although there are many levels of investment which pay for themselves, there is only one optimum. The optimum is the point at which net savings are maximized, R_{opt}. Graphically, it is the point where the slope of the total savings curve is equal to the slope of the total cost curve. (By differentiating both the total cost and the total savings functions, the mathematical requirement for maximizing net savings is obtained -- that is, marginal cost equals marginal savings.)

In order to determine the optimal level of investment in an architectural option, the following information is needed:

1. The life-cycle cost of the architectural option

2. Average annual energy savings from the architectural option

3. Current fuel costs

4. The present value factor for future energy savings over the
    life cycle.

10.1   LIFE-CYCLE COST OF ARCHITECTURAL OPTIONS

10.1.1   First Costs

Attached to this section are the life-cycle cost work sheet (Figure 6),
and the assumptions for a life cycle of 20 years. The first cost
pricing assumptions for selecting the optimum combinations of weather-
ization options are in Appendix D. The data for first cost will be
collected from a variety of sources, including local CAA's, Building
Weatherization Data Sheets (CSA Form 481), construction suppliers'
catalogues, department store catalogues and the 1977 Means Building
Construction Cost Data guide. The cost data will be broken down into
a component for labor and a component for materials.

Two sets of cost estimates will be developed. The first will be based
on the assumption that the weatherization options are installed by the
local Community Action group. The second set will assume that the
weatherization options are installed by a commercial building contractor.
The cost of "preparing" an unusual condition prior to installing a
weatherization option is not considered in selecting optimum combinations
of weatherization options for the demonstration.

This cost will be included in an analysis of the cost data generated by
actual demonstration weatherization.

10.1.2   Assumptions For A Life-Cycle of 20 Years

Some of the architectural options are not expected to have a 20-year
physical life. In order to make the present costs of all the options
compatible with the assumption of a 20-year life, the first costs of
the options must be adjusted to reflect the present value of costs of
any replacements needed within a 20-year period. In order to make esti-
mates of the likely needs for replacement of options, the expected life
of the various options has been evaluated, using the factors listed in
Table 2. A materials technologist has reviewed published literature,
surveyed other authorities in the field and referenced existing standards
to develop the frequency of replacement estimates listed in Table 3.
Those options not listed in Table 3 are not expected to require any
replacement before the 21st year. The replacement assumptions listed
in Table 3 will be included in the present cost estimates, using a 6%
real discount rate. A zero real price increase in the cost of the

18

TABLE 2

FACTORS TO BE CONSIDERED IN EVALUATING AND PREDICTING
THE LIFE OF BUILDING MATERIALS

ENVIRONMENTAL CONDITIONS:

> Moisture
> High temperature
> Low temperature
> Cycling conditions
> Pollution
> Mold
> Occupant Exposure
> Solar radiation

MATERIAL PROPERTIES:

> Hardness
> Strength
> Flexibility
> Permeability
> Acidity
> Alkalinity

FUNCTIONAL REQUIREMENTS:

> Resist ultraviolet radiation
> Insulate
> Resist impact
> Open, close
> Resist abrasion
> Resist corrosive environments
> Expand - contract

architectural options will be assumed. Option costs, with necessary
replacements factored in, will be summarized on the form shown as
Figure 6.

TABLE 3

ESTIMATES OF THE FREQUENCY OF REPLACEMENT OF SEVERAL
ARCHITECTURAL OPTIONS TO ACHIEVE A 20 YEAR PHYSICAL LIFE

OPTIONS NOT HAVING 20 YEAR PHYSICAL LIFE	REPLACEMENT ESTIMATE
Replace broken glass	Replace 2.5% of glass area at end of 10th year.
Reset glazing	Replace 10% of glazing at end of 10th year.
Low emissivity film	Replace 100% of film at years 9 and 18.
Weatherstrip windows	Replace 25% of weatherstripping at end of 10th year.
Caulk windows	Replace 25% of caulking at end of years 8 and 16.
Insulating drapes	Replace 100% of drapes at end of year 10.
Storm door	Replace 25% of door cost at end of year 10.
Weatherstrip doors	Replace 25% of weatherstripping at end of years 5, 10, and 15.
Caulk doors	Replace 50% of the caulking at the end of the 10th year.
Replace threshold	Replace 100% of the threshold at the end of the 10th year.
Attic insulation	Replace 25% of blown-in insulation at end of 15th year.
Weatherstrip attic hatch	Replace 100% at end of 15th year.
Carpet floor	Replace 100% at end of years 7 and 14.

FIGURE 6

LIFE CYCLE COSTS OF ARCHITECTURAL OPTIONS WORKSHEET
(ASSUMES A 6% REAL DISCOUNT RATE)

	11 YEAR		20 YEAR	
ARCHITECTURAL	INSTALLED BY CAA	CONTRACTOR INSTALLED	INSTALLED BY CAA	CONTRACTOR INSTALLED
Replace Broken Glass in Window				
Reset Glazing in Window				
Install New Threshold				
Seal Up Structural Cracks Masonry				
Seal Up Structural Cracks Wood or Asbestos				
Seal Up Structural Cracks Veneer				
Weatherstrip Window				
Caulk Window				
Weatherstrip Exterior Door				
Caulk Exterior Door				
Weatherstrip Attic Hatch				
Install Standard Storm Window				
Install Plastic Storm Window				
Install Insulating Drape				
Install Insulating Shutter				
Install Low Emissivity Films				
Install Standard Triple Glazing				
Install Plastic Triple Glazing				
Install Storm Door				
Install 2nd Wood Door				
Replace Exterior Door W/Insulating Door				
Install - Attic Insulation (R = 19)				
Install - Attic Insulation (R = 30)				
Install - Attic Insulation (R = 38)				
Install Wall Insulation Masonry Wall -- Interior (R = 11)				
Install Wall Insulation Masonry Wall -- Exterior (R = 11)				
Install Wall Insulation Wood Frame (R = 11)				
Install Wall Insulation Veneer Wall (R = 11)				
Install - Floor Insulation (R = 19)				
Install - Floor Insulation (R = 30)				
Carpet Floor				
Install Basement Wall Insulation				
Install Perimeter Slab Insulation				

10.2   ANNUAL ENERGY SAVINGS OF ARCHITECTURAL OPTIONS

Several methods may be used to calculate the reduction in energy use (actually, the decrease in building thermal load) that can be achieved with the various weatherization options. Of these, three have been considered: use of the BLAST computer program (Ref. 4), the NBSLD computer program (Ref. 5), or the standard ASHRAE degree-day calculations (Ref. 6). From these, ASHRAE degree-day calculations have been selected as a means of calculating savings associated with individual architectural options, and the BLAST computer program has been selected to calculate savings associated with combinations of options. However, a number of problems have been encountered with BLAST which still need to be resolved before BLAST can be used satisfactorily for the demonstration. Types of problems that must be resolved are: 1) "bugs" in the program--that is, the program does not perform as its original programmer intended; 2) selection of proper input data--for example, how thick should the earth be between basement floor and a fixed ground temperature; 3) inadequacies in the program--for example, no building energy analysis program properly handles managed drapes. Nevertheless, no other valid way of calculating the effect of combinations of options is known, and BLAST is the best choice from existing programs. If the program is not running properly when required by this project, architectural options will be selected on the basis of their ASHRAE calculations and the effects of combinations of options will have to be evaluated in the demonstration. See Appendix E for the ASHRAE calculations which may be used to estimate energy savings.

10.3   FUEL COST

In order to convert energy savings expressed in Btus to dollars, information on the cost of fuel per BTU is required. Since fuel prices vary both with time and as a function of the region of the country, reliable up-to-date fuel cost estimates are necessary. This task will be accomplished in two stages. In the first stage, data from the latest available fuel bills as received for the demonstration houses will be compiled. These data will be compiled by site, and averaged (for each fuel type) over the sample of dwelling units submitted by the local CSA groups. It should be noted that these fuel records are likely to come from several local fuel companies, so that they should be representative of the prices charged within the demonstration region. In the second stage, the local CAAs and the fuel companies will be contacted to check these figures and determine whether more up-to-date prices are needed.

10.4   PRESENT VALUE FACTOR

The present value factor for future energy savings is a means by which cost savings which occur in the future can be brought back to the present (or "recovered") so that they can be compared to the present cost of an option. The present value factor includes the real rate of fuel price escalation, the real discount rate, and the length of the life cycle under study. The combination of these three inputs yields the present

22

value factor, PVF. The present value factor may be expressed by the
following formula:

$$PVF = \frac{1 + P}{D - P} \cdot \left[1 - \left(\frac{1+P}{1+D} \right)^{L} \right] \qquad \text{if } D \neq P \qquad (2)$$

$$= L \qquad\qquad\qquad\qquad\qquad \text{if } D = P \qquad (3)$$

where P = the real rate of fuel price escalation
      D = the real discount rate
      L = the length of the life cycle in years.

Note that, if D is greater than P then D-P is greater than zero and
((1+P)/1+D)) is less than 1, thus both parts of equation 2 are positive
which implies that their product is positive. If D is less than P, then
D-P is less than zero and ((1+P)/1+D)) is greater than 1, thus both parts
of the formula are negative which again implies that their product is
positive. If D is equal to P, L'Hopital's rule (Ref. 7) must be used to
show that the present value factor is equal to L. Thus, in all three
cases, the present value factor is positive.

10.4.1   Real Fuel Price Escalation

An important ingredient in the present value factor is an estimate for
the long term rate of fuel price escalation. Past experience has shown
that estimates of the long term (20-25 year) rate of fuel price escala-
tion are extremely variable. Ranges of real rates between 0 (constant
energy costs) and 12% (more than tripling every ten years) have been used
in recent economic studies. Although ranges might be useful to see how
sensitive a weatherization option is to rising fuel prices, they do not
enable us to reliably make tradeoffs. In order to do this, a specific
estimate within the range is needed. Several Federal agencies which own
and operate buildings are required to perform economic analyses of poten-
tial energy conserving options which are available to them prior to
construction or renovation. The Department of Defense is one Federal
agency which has made public the forecasts it uses for long term real
rates of fuel price escalation. These rates are summarized in Table 4
(Ref. 8).

10.4.2   Real Discount Rate

Future savings, like future costs, must be discounted. Discounting is
accomplished by means of the real discount rate. A discount rate is that
rate of interest which reflects the time value of money. (The time value
of money is the difference between the value of a dollar today and its
value at some future time if invested at a stated interest rate.) That
is to say, a dollar today is worth more than a dollar in ten years, apart
from inflation. The discount rate may be used to bring any future costs
and savings back to the present so that all options can be compared on
an equivalent basis. A real rate is a value expressed in constant terms

23

TABLE 4

REAL RATES OF FUEL PRICE ESCALATION
USED IN ECONOMIC ANALYSES

FUEL	RATE
Oil	8%
Coal	5%
Natural Gas	8%
LPG	8%
Electricity:	
New England	7%
Pacific	7%
All Others	6%

(e.g., "constant dollars" have been used in order to remove from the cal-
culation the reduction in purchasing power due to inflation). Therefore,
a real discount rate may be thought of as that rate which treats future
costs and savings in terms of constant dollars (1977 dollars will be
assumed in the analysis of option savings). Since low-income families
tend to be borrowers, the rate chosen to reflect their time value of
money should be tied to lending rates. Furthermore, since lending rates
for home improvements tend to be somewhat lower than those for other
goods and services, these rates are the most appropriate for use as a
reference point. The anticipated long term (20-25 year) rate of infla-
tion (6%) is then subtracted from this interest rate (12%) to get the
real discount rate (6%).

10.4.3 Length of Life Cycle

The cost of an option over the life cycle is equal to the first cost
(i.e., the installation cost) plus any future costs resulting from
maintenance, repair or replacement, discounted to a present value.
Using a 20-year life and a 6% real discount rate, the life-cycle cost
of an option, C, may be expressed mathematically as

$$C = C_o + \sum_{t=1}^{20} (C_t/(1.06)^t) \qquad (4)$$

24

where C_o = the installation cost, and
C_t = the costs for maintenance, repair, or replacement occurring in year t (C_t may be equal to zero).

Combining the information on life-cycle cost with life-cycle savings provides us with a means of comparing alternative weatherization options. If the option, such as caulking or weatherstripping windows, produces greater life-cycle savings than costs, then it is economically viable (i.e., it pays for itself). For programmatic purposes it has been decided that the life-cycle to be examined will be a 20-year period. Estimates of the needed replacement of some options over a 20-year period have been listed in Table 3.

11. INSTALLATION OF WEATHERIZATION OPTIONS

Once the architectural and mechanical options have been selected by NBS, they will be telephoned to the local CAA coordinator responsible for working with NBS. The coordinator will prepare, from the list of options a CSA Summary of Work Program and Budget Sheet and a CSA Program Account Budget Sheet. These sheets will list the cost of each option on each house and the total cost for weatherizing each house separately. After these sheets have been prepared, they will be checked with NBS by telephone, and then sent to NBS and CSA in Washington for approval and signature. Once the coordinator receives approval of the options, he will have to work with local contractors or CSA work crews to get the options installed and the required cost data collected. Although NBS will provide guidelines on the selection and installation of the materials to be used in various weatherization options, and the potential hazards in the work, it will be the responsibility of the local CAA coordinator to see that the options are properly installed and that they meet local codes. In order to accomplish this it is suggested that the local coordinator have 26 each house inspected for potential code problems and hazards before any work is done.

12. MONITORING COSTS OF OPTIONS DURING INSTALLATION

The collection of cost information is of crucial importance in the weatherization demonstration program. A good set of detailed cost information is needed for verifying the weatherization options selection process and to provide a sound basis for future weatherization planning and budgeting. Selection of an "optimum" weatherization package weighs expected energy savings against the estimated cost of the option. However, the "optimum" weatherization packages actually being installed are based, of necessity, on forecasts which have been simplified. Similarly, the expected energy savings figures are based on calculations which include additional simplifying assumptions. Consequently, the information collected in the field by CSA and analyzed by NBS on both actual cost and actual energy savings may show that greater cost effectiveness could be achieved if a different combination of weatherization options were installed. In order to improve the chance of identifying the most costeffective combination of weatherization options for future programs, it is necessary to develop a cost estimation procedure which

permits "real world" considerations to enter into the cost calculations. Such considerations include the size of the dwelling unit, the condition of the different building elements, and the wage rates paid to workers doing the weatherization job. The use of this procedure should permit the ultimate achievement of more weatherization per dollar spent. This should permit field offices to operate with greater flexibility in the future budgeting and forecasting of program costs, so that more houses can have the most cost-effective combinations of weatherization options installed.

12.1   Types of Cost Data to be Collected: Cost Definitions

Before the cost data collection forms are explained, it is useful to identify the types of cost information the project will collect.

The cost of installing a weatherization option includes payments to labor, payments for materials, equipment rentals, and any overhead costs that should in principle be assigned to that task. The difference between the bid price, i.e., the contract amount for which the contractor agreed to do the work, and the total labor, materials, equipment and overhead costs represent the contractor's pretax profits. Those costs that the contractor incurs if he undertakes a specific job (i.e., labor costs, including fringe benefits, social security, workmen's compensation, and unemployment insurance, and the cost to the contractor for materials and equipment purchase/rental) are called direct costs. Note that the direct cost for installing a weatherization option is by definition equal to the sum of the labor costs, material cost, and any special equipment costs. Direct costs include preparation cost, installation cost, and other miscellaneous costs. Labor costs, however, may be divided into two parts: 1) direct labor costs which can be associated with one particular weatherization option (such as caulking around windows) and 2) indirect labor charges that cannot be associated with any particular weatherization options, but can be associated with a particular contract. Examples of indirect labor costs are travel time and time spent picking up building materials at the warehouse or lumber yard.

Those costs that the contractor incurs regardless of whether he undertakes a specific job or not, (e.g., rental payments, debt service payments, payments for equipment, payments for clerical and secretarial staff, and payments for management) are called overhead costs. Also of interest is the size of the contractor's markup. The bid price divided by the sum of the direct costs in the contract yields the percentage markup. Markup, therefore, includes both overhead costs and pretax profits. Figure 7 summarizes the cost data required. Previous experience indicates that better quality cost information can be collected if one member of the project is assigned as coordinator, and meets with contractors on a regular basis. This facilitates control of the operation and helps in determining the appropriate action to be taken if any cost information is found to be lacking. It is not desirable to wait until the contract has been completed to request the cost data, since the

reliability of the data will then depend more on the contractor's memory than on documented figures.

FIGURE 7

REQUIRED COST DATA

TYPE OF COST	REPORTING REQUIREMENTS
Bid Price	Each Contractor*
Direct Costs** Labor	
Direct Labor	Each Option, Each Dwelling Unit
Indirect Labor	Each Contract
Materials	Each Option, Each Dwelling Unit
Equipment	Each Option, Each Dwelling Unit

   * Contracts should be numbered, for example from 1 to N, so
     That all direct costs associated with that contractor can
     be traced back to the parent contract.
  ** Direct costs include preparation costs, installation costs
     and other miscellaneous costs.

12.2 FORMS FOR COST DATA COLLECTION

Two basic cost data collection forms will be used. The first form is concerned with direct labor, material, and equipment charges (Figure 8). This form will be filled out for each weatherization option and for each dwelling unit. The second form is concerned with indirect labor charges (Figure 9). This form will be completed for each contract.

First consider the form for recording the direct costs for labor, materials, and special equipment. On this form there is a space for the address of the dwelling unit (a contract ID number should also be entered), when the work was started and when it was finished, the building element to which the option was applied, and the name of the option. Beneath this information are listed three types of work which can be performed: 1) preparation, 2) installation, and 3) other. Associated with each of these types of work are direct labor charges, materials used, and/or equipment rented. Direct labor charges are identified by skill type, for example, carpenter, painter, laborer. The number of hours expended on a task for each type of skill is entered on the same line, for example eight hours for the carpenter, three hours for the painter, ten hours for the laborer. Hourly wage rates are entered in the third column, for each type of skill. (It is not intended that any individual be identified; our focus is on determining the role that labor inputs play in causing costs to vary, and not on the wage or productivity

27

of any individual.) Also associated with each of the three types of work are material and special equipment usage. This information will make it possible to identify the material and equipment needs associated with the installation of the various weatherization options. In the first

FIGURE 8

DWELLING UNIT COST

DATA FORM

Date Started _____
Date Finished _____
Address _____
Building Element _____
Method Used _____

Type of Work	DIRECT LABOR USE			MATERIALS & EQUIPMENT USE			
	Labor Skill	Hours	Rate	Materials/Equipment Type	Unit Size	Time in Use or Quantity	Unit Cost
Preparation							
Installation							
Other							

28

FIGURE 8 (CONT.)

TYPE OF WORK DEFINITIONS

PREPARATION

Those tasks which must be done prior to the actual installation of the weatherization option. This category includes tasks such as job set up and any necessary repairs or replacement of building elements. Preparation should not include indirect labor costs.

INSTALLATION

Those tasks that are involved in the normal installation process for the paticular weatherization option. This includes such activities as finish painting and clean up.

OTHER

Those tasks which are not normally involved in the installation of the particular weatherization option. This category is different from "preparation" in that it includes such tasks as equipment repairs and work stoppage.

FIGURE 9

INDIRECT LABOR COSTS DATA FORM

CONTRACT NUMBER ____

INDIRECT COST ITEM		LABOR TYPE 1		LABOR TYPE 2		LABOR TYPE 3		OTHER	
DESCRIPTION	ID #	WAGE	HOURS	WAGE	HOURS	WAGE	HOURS	COST	AMOUNT

FIGURE 9 (CONT.)

INDIRECT LABOR COSTS DATA FORM

Indirect labor costs are those costs which cannot be linked to a specific weatherization option. Below is a list (not exhaustive) of the kinds of indirect labor costs that may be associated with the installation of the weatherization options.

CONTRACT SPECIFIC INDIRECT COSTS

1. Travel Time

2. Down time

3. Clean-up time (if not attributable to a specific weatherization option)

4. Equipment costs (if not attributable to a specific weatherization option)

column, the type of material or equipment is identified, for example, caulking compound. In the second column the unit size is recorded, for example, 20 oz. tube. In the third column the time in use (for special equipment, such as blowers or heaters) or the quantity used is entered, for example, seven tubes. In the final column the unit cost, or rental rate, for the material or equipment is entered, for example, $2.00 per tube. Additional information about filling out the form is given on the back of the form (see Figure 8 Cont.).

Figure 9 displays the data collection form for recording "indirect labor costs." This form will not have to be separately completed for each option and each dwelling unit. It will only be necessary to fill in one indirect labor cost form for each contract. However, since indirect labor costs will occur irregularly (for example, down-time because the dwelling unit occupants may not be at home), these costs should be recorded on the form when they happen, in order to avoid reporting errors due to faulty recall. The first column of the indirect labor cost data form asks for a brief description of the indirect cost time. Also, if possible, a dwelling unit ID number should be reported along with the brief description, for example, travel time between dwelling units 34 and 35. The following three columns labeled "labor" with sub-headings for wage rates and hours enable differing labor rates to be associated with the described time. If more than three categories of labor are involved the next line can be used. A fourth column headed by "other" is included in order to capture related costs other than labor. For example, travel-time between dwelling units 34 and 35, may involve the cost of operating a vehicle used in that period. On the back side of this form (see Figure 9 Cont.), a brief definition of indirect labor cost is given. Also on the back are a few examples of indirect labor costs that are likely to arise.

13. COLLECTION OF UTILITY DATA

Energy usage, water usage, furnace run times and cycles, and interior temperatures and humidity will be recorded and submitted to NBS on a weekly basis by CSA on forms supplied by NBS, starting as soon as the sample homes are selected and necessary meters are installed as described earlier. These readings will be reported to NBS on a weekly basis until sufficient data has been collected to evaluate the effect of weatheriza-tion on energy consumption. Data on amount of gas or oil delivered and electricity used and the reading dates (similar to data reported for the houses before weatherization) will also be collected from utility and fuel companies on a monthly basis and reported to NBS. These two types of data, those collected by the CSA coordinator and those collected by the utility company, will provide a double check on energy consumed. In cases where significant temperature changes occur because of change in thermostat setting or nighttime setback, as determined by interior tem-perature readings, a method for normalizing the data for this tempera-ture change will be used. One possible normalization method is to raise or lower the base temperature at which the balance point calculations are done to correspond to the change in interior temperature.

14. COLLECTION OF BUILDING DIMENSIONS

In order to compare the savings in one house to those in another,
several normalizing factors have to be used to allow for differences
between these houses. One of these factors is the design load for
each of the houses. This factor takes into account the square footage,
the volume of the house and the type of construction of the house. The
design load for each house will be calculated using standard ASHRAE
type calculatons. In order to perform these calculations, the data
described in Appendix F will be collected by CSA on each house at each
site, and the U values of building components will be modified where
appropriate based on the thermographs made of the building.

15. RECORDING OCCUPANCY CHARACTERISTICS

Other studies have shown that similar homes can vary widely in energy
consumption, apparently as a consequence of the activities of the res-
pective occupants and the different ways that they operate the energy-
using systems (e.g., space heating, appliances, lights) in a building.
The Twin Rivers Program on Energy Conservation in Housing, being con-
ducted by researchers at Princeton University, has documented a range
of two to one between high and low space heating fuel usage for vir-
tually identical middle-income townhouses (Ref. 9).

This being so, it can be assumed that the activities of low-income
residents can have significant influence on the energy consumption of
their homes -- perhaps even effects large enough to partially "mask"
the effects brought about by weatherization.

In evaluating, for individual dwellings, the reduction in energy con-
sumption brought about by weatherization, the effects of occupant
activities on the comparisons will be minimized if the same household
is occupying each building during the monitoring period before and after
weatherization. This situation would lend support to the assumption
that the same individuals were residing in the house during both mea-
surement periods, and that they were using the energy-affecting systems
in substantially the same ways. There could still be differences that
could significantly affect energy consumption, even within the same
household: A parent/grandparent could join -- or leave -- the household.
A household member could be employed at one time -- leaving no one at
home during the daytime -- and unemployed, at another time -- and at home
daytimes. In making the preto post-weatherization comparisons, we will
take note whether the same household occupies the building during the
entire measurement period in order to avoid "confounding" the weatheri-
zation results with differences caused by occupant activities.

To help in evaluating possible occupant effects on energy consumption,
additional information about dwelling occupants and their activities is
required. More detailed information about household members: ages, and
living patterns (e.g., employed daytimes, in school, preschool,
housewife/mother), day and night thermostat settings, use of appliances,

33

and use of hot water will be needed. In order to collect this information a questionnaire will be developed by NBS. The questionnaire will probably be administered in face-to-face interviews by local CSA personnel rather than by having the occupant complete the form on their own.

16. TESTING OF BUILDING ENVELOPE

Building envelope tests will be conducted, by CAA personnel under direction of NBS, on each sample dwelling after weatherization in order to determine the effectiveness of the architectural weatherization options. These tests will be conducted before as well after weatherization on at least five dwellings in each city and will include thermography, infiltration measurements, and fan pressurization tests. Temperature stratification in living spaces will be measured during the heating season. Where necessary, a special test for the existence of heat by-pass mechanisms will be carried out. (Previous studies have found that, in some dwellings, hidden paths permit heated air to escape from living spaces into the attic.)

The following test procedures have been developed:

16.1 THERMOGRAPHIC SURVEY TO LOCATE HEAT LOSSES FROM THE DWELLING (Ref. 10)

In order to locate the heat losses from the exterior building walls and roofs, an exterior thermographic survey is to be performed. This survey should be done in the evening (two hours after sunset on a sunny day) or on a cloudy day and with a temperature difference of at least 15°F between the interior of the dwelling and the outside. The heating system should be operating during the time the survey is performed to assist in localizing possible mechanical system losses. (This can be accomplished by raising the thermostat 10°F so that the furnace operates continuously.) Photographs of thermograms covering approximately 15' x 15' areas should be taken such that a complete thermal image of the walls and roofs can be constructed.

The location of each thermogram should be noted on a corresponding normal photograph of the dwelling section and the day, time, interior temperature, and exterior temperature, wind speed and wind direction (from Weather Service records) should be recorded. A data form will be supplied by NBS for each dwelling.

16.2 DETERMINATION OF ACTUAL AIR LEAKAGE RATES (Ref. 11)

The actual air leakage rates existing in the sample homes will be determined using a sample bag-tracer gas technique developed by NBS. This technique consists of introducing a small amount of a harmless tracer gas (sulfur hexaflouride, SF_6) into a dwelling, and then determining the rate of decay of the tracer gas by analyzing sample bags filled at intervals of an hour. This test will be performed in five dwellings in each

city before weatherization and in all dwellings after weatherization. Since the rate of air leakage is weather dependent, this test will be done under several weather conditions (hopefully at two week intervals throughout the heating season).

NBS will provide specifications for the purchase of sample bags and SF_6 tracer gas bottles. The conditions under which the test is to be performed will depend on the type of heating system in the building:

1. Forced warm air

The furnace fan should be turned on and the tracer gas bottle opened in front of the return air register. Wait approximately 20 minutes for the gas to distribute uniformly into all parts of the building (to a level of approximately 30 parts per billion). Then fill a sample bag labeled "initial reading, dwelling number _____, time to the minute _____." After the sample bag is filled, turn the furnace fan to its normal position. Approximately two hours later return to the building, turn the furnace fan on for ten minutes and then fill a sample bag labeled "final reading, dwelling number _____, day _____, time to the minute _____." Be sure to use the same watch for both readings.

2. Other types of Heating Systems (no furnace fan)

A bottle of tracer gas should be opened on each floor of the dwelling, being certain that all interior doors are open (a door from the interior to an enclosed porch should be left in its normal position for heating the building). Small portable fans should be placed in the doorways between rooms and turned on for approximately 1/2 hour in order to distribute the tracer gas as well as possible. A sample bag should then be filled for each floor and labeled "initial reading, dwelling number _____, floor number _____, day _____, and time to the minute _____." The fans should then be turned off. In approximately two hours return to the dwelling, turn on the fans for ten minutes and then fill a sample bag labeled "final reading, dwelling number _____, floor _____, day _____, and time _____."

During these tests it is important that exterior doors or windows be left closed, except for normal entering and leaving of the building.

16.3 DETERMINATION OF THE TIGHTNESS OF THE BUILDING ENVELOPE BY PRESSURIZATION (Refs. 12, 13, 14)

A second method for assessing the tightness of the building envelope is the fan pressurization test. A large fan and a pressure gauge will be required for performing this test. Each site will have to construct an assembly to fit in a door according to NBS specifications. The tightness of the building will be determined in this test by measuring the pressure drop across the building for various flow rates of the fan. This test will be done in each home once before and once after weatherization during the milder seasons of the year when little or no heating is required.

16.4 DETERMINATION OF INTERIOR TEMPERATURE STRATIFICATION

The temperature in each room should be measured 6" above the floor (T_F), 3 ft. above the floor (T_M) and 6" below the ceiling (T_C) during the heating season. This data should be reported on a floor plan of the dwelling, for example:

Front
Door

Living Room	Dining Room	Bedroom	Bedroom
T_C = 72	T_C =	T_C = 80	
T_M = 70	T_M =	T_M = 75	
T_F = 63	T_F =	T_F = 70	

Recreation   Kitchen T_C = 80
   Room

1st Floor Plan   2nd Floor Plan

16.5 PRESSURIZATION – INFRARED TEST PROCEDURE FOR LOCATING AIR LEAKAGE
     PATHS (Ref. 14)

While the previously described test procedures determine the amount of air leakage the house is experiencing, they do not identify the specific locations of leakage paths. This will be accomplished by depressurizing the building using a blower fan, and using an inside infrared inspection procedure to find air leaks. This test can serve as a means for determining the effectiveness of the caulking and weatherstripping in sealing air leakage paths. The test will be done in houses which, after weatherization, still exhibit high air leakage rates according to the results of tests described under Determination of Actual Air Leakage Rates and Determination of Tightness of the Building Envelope by Pressurization.

16.6 TEST TO DETERMINE THE EXISTENCE OF HEAT BY-PASS MECHANISM INTO
     THE ATTIC (Ref. 15)

Previous studies, such as those done at Twin Rivers, New Jersey, have shown that there exist many paths by which heat can escape from a dwelling and, in effect, by-pass insulation. A substantial portion of this heat usually flows into the attic, and this source of heat loss can be detected by making night-time air temperature measurements in the attic, outdoors, and at the ceiling adjacent to the attic. By comparing these temperature data with temperatures predicted by standard heat load calculations for the level of insulation in the attic, the presence of such paths can be detected.

17. RE-TESTING OF MECHANICAL SYSTEM

Tests will be performed on the heating system in each dwelling in order to determine the seasonal efficiency of the system after weatherization.

36

This test basically consists of the standard steady-state efficiency test described in Appendix B, plus the additional measurement of the stack temperature at specific times in the heating and cool down cycle of the heating system. This data will be used in computer programs developed by NBS to determine the seasonal operating efficiency of the system.

18. ANALYZING COLLECTED DATA

The design of this demonstration lends itself to analysis of collected data which can lead to an understanding of the major parameters which affect energy savings and the cost of weatherization options. The parameters affecting energy savings which will be examined are: infiltration, conductive heat loss, radiant (solar) heat gain, mechanical efficiency, internal loads, interior temperature and interior humidity. The parameters affecting cost which will be examined are: preparation cost, material and labor cost associated with the installation of weatherization options, and frequency of replacement.

Measurement of these variables will be used to explain variations in savings and costs between houses and sites.

Information on the pre- and post-retrofit condition of demonstration homes will be used to assess differences in savings and costs (especially preparation costs) between demonstration sites as well as between houses in the same site.

The data on costs will be collected using the forms in Figures 8 and 9 (pages 30-33). A preliminary analysis will involve comparison of estimated cost and actual cost. The installation of each option will also be carefully examined and the frequency of replacement values contained in Table 3 reevaluated. Formulas based on regression analysis will then be derived from the collected data. These formulas will permit costs to be accurately predicted based on a small number of key factors. The cost estimation procedure will be designed so that it is flexible enough to deal explicitly with labor, material and preparation costs for each option at each site.

The primary measures of the savings of each dwelling will be the K-factor, which is the energy consumption per degree day, and the balance point, which is, roughly, the average outside temperature below which the heating system turns on. These two parameters for the pre- and post-weatherization fuel usage of each dwelling allow an accurate assessment of the savings accrued for each dwelling. They do not in themselves, however, explain the reason for the savings. Building envelope tests and mechanical systems tests will provide additional data for understanding dwelling performance (see pages 36 to 39).

Statistical regression and correlation analysis of the data gathered from these tests will be undertaken to obtain the functional relationships, f and g, between the independent and dependent variables as follows:

$$B_1 = f(H_c, H_a, EFF, S_g, E) \tag{5}$$

$$T_0 = g(H_c, H_a, EFF, S_g, E) \tag{6}$$

B_1 = K-factor or slope of best fit line (least squares fit) from balance point calculations. Its dimensions are Btu consumption per degree day, using the balance point of the house in question as the base temperature for calculating degree days.

T_0 = Balance point, the outside temperature (in °F) below which the heating system comes on.

H_c = Conductive heat loss factor, the sum of the areas of various types of construction times their respective U-values.

H_a = Infiltration heat loss factor (per hour, per °F)
($=C_p$ x V x AI)

C_p = The specific heat of air (0.018 Btu/ft^3·°F)

V = Volume of the house in cubic feet

AI = Air infiltration rate in cubic feet per hour, derived from tracer gas test or fan pressurization test.

EFF = the efficiency of the heating system

S_g = solar heat gain of the house, derived from calculations using the best available solar data for each site.

E = energy usage for non-space heating purposes.

This type of analysis will be performed on both the pre- and post-weatherization data from the houses, to aid in assessing the differences in B_1 and T_0 resulting from weatherization. From this analysis of the data, average percentage savings and energy consumption before and after weatherization will be derived for each fuel type at each site.

19. DISSEMINATION OF RESULTS

A quarterly report with an executive summary will be delivered to CSA on the progress of the project. Six NBSIR reports, with executive summaries, as listed and described below will be delivered in draft form at various points during the project and in final report form with an executive summary at the end of the project. These reports will also be provided to the Community Action agencies for use by such agencies.

19.1 REPORTS

1. Weatherization Retrofit Options - This report will provide a complete list of weatherization retrofit options along with

a discussion of the estimated costs, maintenance problems, durability problems and safety problems associated with each.

2. Predicted Optimum Combination of Weatherization Retrofit
    Options Throughout the U.S. - This report will describe
    optimum packages of retrofit options for each of the climate
    areas identified in Figure 2. The selection of options for
    these packages will be based on estimated costs, professional
    judgment, computer modeling, and the best state-of-the-art
    knowledge.

3. Cost of Materials, Labor, and Job Preparation for Installing
    Weatherization Retrofit Options Throughtout the U.S. - This
    report will provide CSA with a method of estimating, in the
    field, the cost of various retrofit options. It will also
    report on installation problems and costs for various
    weatherization retrofit options based on field observation
    in the 16 climate areas identified in Figure 2.

4. Technique for Field Evaluation of Energy Conservation - This
    is a plan for research that will take place in FY 79. This
    report will describe and discuss various techniques, such as
    fan pressurization tests and thermography, which can be used
    in the field for identifying the magnitude of energy consump-
    tion due to infiltration, transmission, mechanical system
    inefficiencies, and poor energy conservation management of
    houses. Past experience with these techniques will be reported
    along with recommendations on how they should be used for this
    project next year.

5. A Study of Mechanical Options for Weatherization - This report
    will address all aspects of weatherizing mechanical systems in
    single-family housing. Based on the field measurements col-
    lected during the project by CSA contractors and NBS, it will
    discuss durability, maintenance, and cost. It will estimate
    and provide field measurements of costs and energy savings
    associated with a broad range of retrofit options.

6. Optimum Weatherization Throughout the U.S. - This is a major
    report resulting from one year of intensive research. It will
    provide a list of optimum combinations of weatherization
    options for each climate area identified in Figure 2. The
    list will be based on field measurements representing the best
    data available on savings, costs, and durability of various
    weatherization options. A methodology will be described in
    part of the report for implementing this data into a possible
    loan program.

1. Workshop to Kick-off Demonstration - As soon as CSA has made
    the money available to the demonstration sites, NBS will con-
    duct a workshop to explain the demonstration. The workshop
    will present this project plan and discuss problems experienced
    in Portland, Maine.

2. Workshop to Exchange Experience Between Demonstration Sites -
    Once all the sites have partially completed installing the
    options, a workshop will be held to exchange information on
    installation, levels of weatherization, cost, etc.

3. Conduct Regional Conferences on Energy Conservation - Once
    the demonstration is complete, a series of conferences will
    be conducted in the various regions to disseminate the infor-
    mation collected by CSA/NBS and the local agencies which were
    part of the demonstration. These conferences will present
    energy conservation findings of the demonstration and other
    available research and will explain how local groups can con-
    duct their own research in order to evaluate the efforts of
    their weatherization.

19.3 BRIEFING

NBS will sponsor jointly with CSA a briefing on the findings of
this research and demonstration project for the Department of
Energy, the Department of HUD, Farmers Home Administration, and
other agencies involved in energy conservation in residences.

APPENDIX A

INSTALLATION OF UTILITY METERS AND THERMOMETERS

In view of the lack of accurate measuring devices in some homes selected for the demonstration, meters, thermometers and other measuring devices have to be installed. The following instruments should be installed.

FURNACES AND SPACE HEATERS

1. a gas meter in the gas supply piping to a furnace or heater.

2. a kilowatt-hour meter in the branch circuit of an electric furnace or individual electric space heaters. (Meter constant should not be larger than 3.6 watt-hours.)

3. a furnace run time meter with a one minute resolution in the hot air fan circuitry or hot water circulatory pump circuitry. In gravity circulating systems or steam systems, the running time meter will be installed in the branch circuit to the furnace.

4. a cycle counter in the gas valve circuitry of gas furnaces (coordinate installation with the local gas company representative).

5. for oil-fired furnaces, a cycle counter and a run time meter with a one minute resolution in the oil pump circuitry.

WATER HEATERS

1. a gas meter in the gas supply piping to a gas fired water heater.

2. a kilowatt-hour meter in the branch circuit of an electric hot water heater (meter constant should not be larger than 3.6 watt-hours).

3. water meter on the cold water supply to each hot water heater. (Meter shall have 0.1 gallon resolution).

ROOM TEMPERATURES

A thermometer having at least a 1°F resolution shall be installed on an interior wall at center of house to read temperature within:

    basement
    first floor
    second floor
    third floor

HUMIDITY

A sling psychrometer should be used by each local agency to determine first floor wet-bulb and dry-bulb readings.

APPENDIX B

INSTRUCTIONS FOR TESTING MECHANICAL SYSTEMS

The following tests are to be performed on the heating and hot water systems by a local heating contractor or CAA as approved by NBS.

FURNACE

1. Measure steady-state efficiency of the furnace by normal CO_2 and flue gas temperature measurements both before and after cleaning and adjusting the furnace. Record the flue gas temperature, CO_2 percentage, the Bacharach smoke number, and the draft above the fire (if possible) and at the flue sample hole on the data sheet "A" provided.

2. Determine before cleaning and adjusting of the furnace the temperature in the plenum at which the fan turns on and off (air system). Record the temperature on the appropriate data sheet (B,C, D, or E).

3. Cleaning and adjusting should consist of:

    a) Clean the heat exchanger.

    b) Replace any defective nozzle or inoperable burner.

    c) Adjust the fan controls such that the temperature in the plenum is 110°F when the fan turns on, and 80°F when it turns off (forced warm air system).

    d) Change air filter (warm air).

    e) Check for air leaks in the furnace.

4. Record input and output ratings of the furnace, the rated capacity of the blower or circulating pump and the nozzle size (oil in gal/ hr) on data sheet "A".

5. Supply a picture of the furnace, if possible, and attach to data sheet "A".

6. Report the condition of the fire box on data sheet "A" and repair if necessary.

7. Report the condition of the heat exchangers on data sheet "A".

8. Make any professional comments and recommendations on data sheet "A" that you feel will lead to better performance of the heating system.

42

DISTRIBUTION SYSTEM

1. Determine steady-state air flows and temperatures in plenum and at
   each register as used by the occupants. Allow system to operate
   continuously for at least 10 minutes before measuring (air system).

   Techniques: At a rectangular plenum, the temperature and air velo-
                city should be measured by probing the supply duct at
                nine points forming a grid as shown in the following
                figure. The flow rate, in cubic feet per minute, is
                determined by multiplying the average velocity by the
                cross sectional area of the plenum, A X B, in square
                feet.

Record the data on Data Sheet "B".

At a circular plenum the temperature and air flow should be determined
by probing at seven points along the plenum diameter as shown in the
following figure and Table 1 (Ref. 16). The air flow rate is determined
by multiplying the average air velocity by the cross section (area of
the duct, $0.785D^2$, where D is the plenum diameter in feet.

Record data on Data Sheet "C".

TABLE 1

LOCATION OF PITOT TUBE TIP ON
PLENUM DIAMETER
(REF. 16)

LOCATION NUMBER & DISTANCE ON DIAMETER – INCHES

DIAMETER OF PLENUM INCHES	1	2	3	4	5	6	7
6	1/4	1	1 3/4	3	4 1/4	5	5 3/4
7	1/4	1	2	3 1/2	5	6	6 3/4
8	1/4	1 1/4	2 1/4	4	5 1/2	6 3/4	7 3/4
9	1/4	1 1/4	2 3/4	4 1/2	6 1/4	7 3/4	8 1/2
10	1/4	1 1/2	3	5	7	8 1/2	9 1/2
11	1/2	1 1/2	3 1/4	5 1/2	7 3/4	9 1/4	10 1/2
12	1/2	1 3/4	3 1/2	6	8 1/4	10 1/4	11 1/2
13	1/2	2	3 3/4	6 1/2	9 1/4	11	12 1/4
14	1/2	2	4	7	10	12	13 1/4
15	3/4	2 1/4	4 1/4	7 1/2	10 1/2	12 3/4	14 1/4
16	3/4	2 1/4	4 3/4	8	11 1/4	12 3/4	15 1/4
17	3/4	2 1/2	5	8 1/2	12	14 1/2	16 1/4
18	3/4	2 1/2	5 1/4	9	12 3/4	15 1/4	17 1/4
19	3/4	2 3/4	5 1/4	9 1/2	13 1/4	16 1/4	17 1/4
20	1	3	6	10	14	17	19
21	1	3	6 1/4	10 1/2	14 3/4	18	20
22	1	3 1/4	6 1/2	11	15 1/2	18 3/4	21
23	1	3 1/4	6 3/4	11 1/2	16 1/4	19 1/2	22
24	1	3 1/2	8	12	17	20 1/2	23
25	1	3 3/4	8	12 1/2	17 1/2	21 1/4	24
26	1	3 3/4	7 3/4	13	18 1/4	22 1/4	25
27	1 1/4	4	8	13 1/2	19	23	25 3/4
28	1 1/4	4	8 1/4	14	19 3/4	24	26 3/4
29	1 1/4	4 1/4	8 1/2	14 1/2	20 1/4	24 3/4	27 3/4
30	1 1/4	4 1/4	9	15	21	25 1/2	28 3/4

44

Temperature and air flow should be probed in the centers of individual supply ducts near the furnace hot air discharge section for distribution systems not using a plenum. Record data on Data Sheet "D" for circular ducts; on Data Sheet "E" for rectangular ducts.

A cardboard box sufficient to cover a 16" x 16" register should be constructed with a 6" or 5" section of duct (seal all holes and cracks in the box such that there are no leaks) and the flow and temperature measured at the duct section (+) (see diagram following).

Record data on appropriate data sheet "B", "C", "D", or "E" depending on the type of hot air distribution system design.

2. For the water systems, measure the return and outlet water temperature when the boiler has been operating for at least 10 minutes by measuring the surface temperature of the metal pipe along an insulated portion of the supply pipe (if the pipe is uninsulated, wrap the pipe with insulation before making the measurement). The temperature measurement should be made through a small hole in the insulation using a heat sink compound on the tip of the thermometer. (Dow Chemical heat sink compound 340). Record data on Data Sheet "F".

3. Inspect each radiator and make note of the percentage of inoperable cells (water or steam system). Record data on either Data sheet "F" (water systems) or Data Sheet "G" (steam systems).

4. On steam systems, check for inoperable steam traps or air vents on single pipe systems. Report inoperable traps or vents on Data Sheet "G" comments.

5. Supply a photograph of any covered or blocked (by furniture, curtains etc.) register, radiator or baseboard heater.

WATER HEATER

1. Perform CO_2, flue gas temperature, and Bacharach smoke number mea-
   surements for oil and gas water heaters, at steady-state conditions.

2. Measure the temperature of the exterior jacket (using heat sink com-
   pound) on the hot water heater, temperature in the space containing
   the hot water heater, and temperature of the cold water and the hot
   water at the nearest faucets.

3. With both hot and cold shower valves fully opened, measure the time
   it takes to fill a five gallon bucket (in seconds) using both hot
   and cold water together. (Do this measurement three times, recording
   results separately).

4. Measure heater recovery time:

   a) Draw hot water until water heater begins to heat.

   b) Wait until the heating stops and shut off heater.

   c) Immediately withdraw 20 gallons (four 5-gallon bucketfulls).

   d) Turn on heater and record the length of time (minutes and
      seconds) needed to regain shutoff temperature (heater "on" to
      heater "off").

   e) Record the wattage rating on electric heater, the burn rate on
      gas or oil heaters.

   f) Make general comments on overall condition of water heater and
      supply a picture of it, if possible.

Record water heater data on Data Sheet "H".

BUILDING HEATING SYSTEM DATA
DATA SHEET "A"

HOUSE REFERENCE NO:_____   DATA:_____

TYPE OF HEATING SYSTEM (CHECK)

____Circulated Water, ____Gravity Water, ____Steam, ____Forced Air, ____Gravity Air

____Venter Space or Room Heater, ____Hot Water Heater Integral with Furnace,

____Unvented Space or Room Heater.

TYPE OF FUEL (CHECK)

____Natural Gas, ____Bottled Gas, ____Oil, ____Kerosene, ____Coal, ____Electricity

COMBUSTION EFFICIENCY OF THE FURNACE

BEFORE CLEANING FURNACE   AFTER CLEANING FURNACE

_____%   _____% CO_2 in flue gas

_____°F   _____°F Flue gas temperature

_____%   _____% Combustion efficiency

_____in. H_2O _____in. H_2O Draft above fire

_____   _____ Bacharach smoke number

RECORD FROM FURNACE NAME PLATE

FURNACE MANUFACTURER'S NAME_____

INPUT RATING_____BTU/HR OUTPUT RATING_____BTU/HR BLOWER RATING_____CFM

Rated Capacity of Circulating Pump _____gpm

Nozzle Size (oil) _____gph

TAKE A PHOTOGRAPH OF THE FURNACE (Attach 1 photo & negative to the back of this sheet)

CONDITION OF FIRE BOX (CHECK)

_____Excellent, _____Good, _____Poor, _____Was Repaired.

CONDITION OF HEAT EXCHANGER (CHECK)

_____Excellent, _____Good, _____Poor.

ANY COMMENTS/RECOMMENDATIONS

Contractors Name, Address, and Telephone Number.

47

AIR DISTRIBUTION SYSTEM (PLENUM WITH
RECTANGULAR CROSS SECTION)
DATA SHEET "B"

HOUSE REFERENCE NO:_____   DATE: _____

1. STEADY STATE AIR FLOW AND TEMPERATURES IN PLENUM AT NINE POSITIONS ACROSS PLENUM
    (see instructions)

    (1) _____ft/min _____°F   (2) _____ft/min _____°F

    (3) _____ft/min _____°F   (4) _____ft/min _____°F

    (5) _____ft/min _____°F   (6) _____ft/min _____°F

    (7) _____ft/min _____°F   (8) _____ft/min _____°F

    (9) _____ft/min _____°F

2. STEADY STATE AIR FLOWS AND TEMPERATURES AT EACH REGISTER USED BY OCCUPANTS.
    DETERMINE BY USING CARDBOARD AIRFLOW SECTION (see instructions).

LOCATION	AIR TEMPERATURE °F	AIR VELOCITY FT/MIN
(1) Kitchen		
(2) Living Room		
(3)		
(4)		
(5)		
(6)		
(7)		

ATTACH ONE PHOTOGRAPH AND NEGATIVE TO THE BACK OF THIS SHEET OF ANY COVERED OR BLOCKED
(BY FURNITURE, CURTAINS, ETC.) REGISTERS. ALSO ON THE BACK OF THIS SHEET MAKE ANY
COMMENTS OR RECOMMENDATIONS.

DETERMINE BEFORE CLEANING AND ADJUSTING OF THE FURNACE THE TEMPERATURE IN THE PLENUM
AT WHICH FAN TURNS ON _____ °F, AND OFF _____ °F.

CONTRACTORS'S NAME, ADDRESS AND TELEPHONE NUMBER

AIR DISTRIBUTION SYSTEM (PLENUM
WITH CIRCULAR CROSS SECTION)
DATA SHEET "C"

HOUSE REFERENCE NO: _____   DATE:_____

1. STEADY STATE AIR FLOWS AND TEMPERATURE IN PLENUM CROSS SECTION AT TEN POSITIONS
    ALONG A DIAMETER (see instructions)

    DIAMETER OF PLENUM _____inches

    (1) _____ft/min _____°F   (2) _____ft/min _____°F

    (3) _____ft/min _____°F   (4) _____ft/min _____°F

    (5) _____ft/min _____°F   (6) _____ft/min _____°F

    (7) _____ft/min _____°F

2. STEADY STATE AIR FLOWS AND TEMPERATURE AT EACH REGISTER USED BY OCCUPANTS.
    DETERMINE BY USING CARDBOARD AIR FLOW SECTION (see instructions).

LOCATION	AIR TEMPERATURE °F	AIR VELOCITY FT/MIN
(1) Kitchen		
(2) Living Room		
(3)		
(4)		
(5)		
(6)		
(7)		

    ATTACH ONE PHOTOGRAPH AND NEGATIVE TO THE BACK OF THIS SHEET OR ANY COVERED OR
    BLOCKED (BY FURNITURE OR CURTAINS, ETC.) REGISTERS. ALSO ON THE BACK OF THIS
    SHEET MAKE ANY COMMENTS OR RECOMMENDATIONS.

    DETERMINE BEFORE CLEANING AND ADJUSTING OF THE FURNACE THE TEMPERATURE IN THE
    PLENUM AT WHICH THE FAN TURNS ON _____°F, AND OFF _____°F.

CONTRACTOR'S NAME, ADDRESS, AND TELEPHONE NUMBER.

AIR DISTRIBUTION SYSTEM (NO PLENUM AND EACH
DUCT OF CIRCULAR CROSS SECTION ATTACHED TO FURNACE AIR
DISCHARGE SECTION)
DATA SHEET "D"

HOUSE REFERENCE NO:_____   DATE:_____

1. RECORD INDIVIDUAL DUCT SIZE, STEADY STATE AIRFLOWS, AND TEMPERATURES IN THE
    CENTER OF EACH DUCT OF CIRCULAR CROSS SECTION (see instructions).

    (1) _____ft/min _____°F _____dia. in.* (2) _____ft/min _____°F _____dia. in.

    (3) _____ft/min _____°F _____dia. in.   (4) _____ft/min _____°F _____dia. in.

    (5) _____ft/min _____°F _____dia. in.   (6) _____ft/min _____°F _____dia. in.

    (7) _____ft/min _____°F _____dia. in.   (8) _____ft/min _____°F _____dia. in.

    (9) _____ft/min _____°F _____dia. in.

*Diameter of Duct in inches.

2. STEADY STATE AIRFLOWS AND TEMPERATURES AT EACH REGISTER USED BY OCCUPANTS. DETERMINE
    BY USING CARDBOARD AIRFLOW SECTION (see instructions).

LOCATION	AIR TEMPERATURE °F	AIR VELOCITY FT/MIN
(1) Kitchen		
(2) Living Room		
(3)		
(4)		
(5)		
(6)		
(7)		

ATTACH ONE PHOTOGRAPH AND NEGATIVE TO THE BACK OF THIS SHEET OF ANY COVERED OR BLOCKED
(BY FURNITURE, CURTAINS, ETC.) REGISTERS. ALSO ON THE BACK OF THIS SHEET MAKE ANY
COMMENTS OR RECOMMENDATIONS

DETERMINE BEFORE CLEANING AND ADJUSTING OF THE FURNACE THE TEMPERATURES IN 1 DUCT
ATTACHED TO FURNACE AIR DISCHARGE SECTION AT WHICH FAN TURNS ON ____°F AND OF ____°F.

CONTRACTOR'S NAME, ADDRESS, AND TELEPHONE NUMBER.

AIR DISTRIBUTION SYSTEM (NO PLENUM AND EACH DUCT
OF RECTANGULAR CROSS SECTION ATTACHED
TO FURNACE AIR DISCHARGE SECTION)
DATA SHEET "E"

HOUSE REFERENCE NO:_____   DATE:_____

1. RECORD INDIVIDUAL DUCT SIZE, STEADY STATE AIRFLOWS, AND TEMPERATURES IN THE CENTER
    OF EACH DUCT OF RECTANGULAR CROSS SECTION (see instructions).

    (1) _____ft/min _____°F _____H* _____W*   (2) _____ft/min _____°F _____H _____W

    (3) _____ft/min _____°F _____H _____W   (4) _____ft/min _____°F _____H _____W

    (5) _____ft/min _____°F _____H _____W   (6) _____ft/min _____°F _____H _____W

    (7) _____ft/min _____°F _____H _____W   (8) _____ft/min _____°F _____H _____W

    (9) _____ft/min _____°F _____H _____W   (10) _____ft/min _____°F _____H _____W

*H = Duct Height, W = Duct Width

2. STEADY STATE AIRFLOWS AND TEMPERATURES AT EACH REGISTER USED BY OCCUPANTS. DETERMINE
    BY USING CARDBOARD AIR SECTION (see instructions).

LOCATION	AIR TEMPERATURE °F	AIR VELOCITY FT/MIN
(1) Kitchen		
(2) Living Room		
(3)		
(4)		
(5)		
(6)		
(7)		

ATTACH ONE PHOTOGRAPH AND NEGATIVE TO THE BACK OF THIS SHEET OF ANY COVERED OR BLOCKED
(BY FURNITURE, CURTAINS, ETC.) REGISTERS. ALSO ON THE BACK OF THIS SHEET MAKE ANY
COMMENTS OR RECOMMENDATIONS.

DETERMINE BEFORE CLEANING AND ADJUSTING OF THE FURNACE THE TEMPERATURE IN 1 DUCT
ATTACHED TO FURNACE AIR DISCHARGE SECTION AT WHICH FAN TURNS ON _____°F AND OFF _____°F.

CONTRACTOR'S NAME, ADDRESS, AND TELEPHONE NUMBER

HOT WATER DISTRIBUTION SYSTEM
DATA SHEET "F"

HOUSE REFERENCE NO:_____   DATE:_____

1. STEADY STATE OUTLET WATER TEMPERATURE TO BOILER

    _____°F

2. STEADY STATE RETURN WATER TEMPERATURE FROM BOILER

    _____°F

3. INOPERABLE RADIATOR CELLS

        LOCATION   NO. OPERABLE CELLS   NO. INOPERABLE CELLS

    (1) Kitchen

    (2) Living Room

    (3)

    (4)

    (5)

    (6)

    (7)

ATTACH ONE PHOTOGRAPH AND NEGATIVE TO THE BACK OF THIS SHEET OF ANY COVERED OR BLOCKED
(BY FURNITURE, CURTAINS, ETC.) RADIATORS. ALSO ON THE BACK OF THIS SHEET MAKE ANY
COMMENTS OR RECOMMENDATIONS.

CONTRACTOR'S NAME, ADDRESS, AND TELEPHONE NUMBER.

STEAM DISTRIBUTION SYSTEM
DATA SHEET "G"

HOUSE REFERENCE NO:_____   DATE:_____

1. STEADY STATE OUTLET STEAM TEMPERATURE FROM BOILER

   _____°F

2. STEADY STATE CONDENSATE RETURN TEMPERATURES

   _____°F

3. INOPERABLE RADIATOR CELLS

   LOCATION   NO. OPERABLE CELLS   NO. INOPERABLE CELLS

   (1) Kitchen

   (2) Living Room

   (3)

   (4)

   (5)

   (6)

   (7)

ATTACH ONE PHOTOGRAPH AND NEGATIVE TO THE BACK OF THIS SHEET OF ANY COVERED OR BLOCKED
(BY FURNITURE, CURTAINS, ETC.) RADIATORS. ALSO ON THE BACK OF THIS SHEET MAKE ANY
COMMENTS OR RECOMMENDATIONS.

CONTRACTOR'S NAME, ADDRESS, AND TELEPHONE NUMBER.

HOT WATER HEATER
DATA SHEET "H"

HOUSE REFERENCE NO:_____   DATE:_____

<u>TYPE OF WATER HEATER FUEL (CHECK)</u>

_____Natural Gas, _____Bottled gas, _____Oil, _____Kerosene, _____Coal, _____Electricity

_____Heater is integral with Furnace.

<u>COMBUSTION EFFICIENCY</u>

_____% CO_2 _____Backarach Smoke Number

_____°F Flue gas temperature

_____% Combustion efficiency

TEMPERATURE ON EXTERIOR JACKET OF HEATER _____°F

AMBIENT AIR TEMPERATURE IN HEATER ROOM _____°F

TEMPERATURE OF HOT WATER AT NEAREST FAUCET _____°F

TEMPERATURE OF COLD WATER SUPPLY _____°F

TIME TO DRAW FIVE GALLONS OF SHOWER WATER (HOT & COLD FULL OPEN)

_____sec.   _____sec.   _____sec.

HEATER RECOVERY AFTER WITHDRAWING 20 GALLONS OF HOT WATER

_____minutes and _____seconds.

<u>RECORD FROM HEATER NAME PLATE</u>

Manufacturer's Name _____

Model Number _____

Size of Storage Tank_____

Rating of Heater_____btu/hr or_____ watts _____gph

<u>TAKE A PHOTOGRAPH OF THE HOT WATER HEATER</u> (Attach 1 photo & negative to the back
                                        of this sheet)

COMMENTS/RECOMMENDATIONS CONCERNING HOT WATER HEATER.

CONTRACTOR'S NAME, ADDRESS, AND TELEPHONE NUMBER.

APPENDIX C

CALCULATIONS FOR MECHANICAL OPTIONS

VENT OR FLUE DAMPERS & RESTRICTORS

The savings for a flue damper or restrictor can vary from system to system; however a relatively conservative estimate can be obtained by using equation (1)(page 20) with N = 0.07.

ELECTRONIC IGNITION (Ref. 17)

The savings for an electronic ignition are estimated by equation (1) with N = 0.07.

TWO STAGE GAS VALVES

DERATE FURNACE (Ref. 18)

Field studies have shown that nozzle and orifice reduction, where possible, can lead to a savings of approximately 4.6%, though this will vary greatly from system to system. If it is possible to reduce excess air at the same time as reducing nozzle size, an average savings of 8% would be possible according to field studies. At present, a 4.6% savings will be assumed. (N = .046)

REPLACEMENT OF BURNER AND/OR FURNACE

The replacement of burners and furnaces may be necessary in many situations where 1) the steady state efficiency of the system is below 65%, 2) the smoke number is above 2, 3) the heat exchanger or fire box is in bad condition and 4) the unit is very old and requires large maintenance costs. The savings from replacing the burner or furnace can be obtained from the equation

$$\text{Savings} = 0.5 \times \text{Fuel} \times \left(\frac{1}{e_b} - \frac{1}{e_a} \right)$$

where fuel is anual fuel consumption, e_b is the annual efficiency before replacement and e_a is the annual efficiency after replacement. The mechanical testing of the furnace gives the steady state efficiency e_{ss} of the system and the balance point calculation allows determination of the oversizing factor by the equation

$$\alpha = B / \left[K \cdot \frac{T_o - T_d}{24} \right] - 1$$

where T_o is the balance point of the dwelling, K is the K-factor (fuel per degree day, see page 9), T_d is the local design temperature and B is the burner nozzle or orifice rate in the same units as K (thus $K \cdot \dfrac{T_o - T_d}{24}$ is hourly heating fuel needed at design load). The seasonal efficiency of the furnace can be approximated by

$$e_s = 0.8 \times e_{ss} - 4 \times \alpha$$

where e_{ss} is the steady state efficiency of the furnace. By performing the above calculations before and after replacement, an estimate of the savings can be made.

INSULATE DUCTS & PIPES

All hot water and steam pipes will be insulated in unheated spaces. Ducts will be insulated where there is more than a 20°F drop between the plenum and the register as determined in the preliminary test. Thickness of insulation will be determined a case-by-case basis.

RADIATOR REFLECTORS

These will be installed on all exterior wall radiators of dwellings at sites where the number of degree days is greater than 4,000.

NIGHT SETBACK THERMOSTAT

The potential saving for a night setback thermostat can be obtained from the equation

$$S_{NS} = 0.5 \times \text{Fuel} \times \eta/100$$

where is given in Table C-1 for each demonstration site for both 5°F and 10°F setback temperatures.

TABLE C-1

PERCENT SAVINGS FOR
NIGHT SETBACK OF THERMOSTAT
(Ref. 19)

	Setback 5 F	Setback 10 F
Albuquerque	8	12
Atlanta	11	15
Charleston	11	16
Chicago	7	11
Colorado Springs	7	11
Easton	8	12
Fargo	5	8
Miami	11	16
Minneapolis	5	9
New Orleans	11	16
Oakland	10	14
Portland	6	9
St. Louis	8	12
Tacoma	8	12
Washington	9	13

RELOCATE THERMOSTAT

Savings for relocated thermostats will be estimated based on anticipated savings from reduced temperatures in overheated spaces.

INSULATE WATER HEATER (R = 7) (Ref. 20)

Electric Water Heater	365 kWh/yr
Gas Water Heater	36.5 therms/yr
Oil Water Heater	25.5 gal/yr

INSTALLATION OF AQUABOOSTER ON TANKLESS COIL FURNACE-WATER HEATER SYSTEMS

In most tankless coil systems the only manner in which a nozzle can be reduced is by installing a hot water storage tank (aquabooster). The expected savings from this option is 12.4%. (N = 0.124)

REPLACE WATER HEATER

Replacement of the water heater will result in estimated savings of

$$13.78 \times 10^6 / (\frac{1}{e_{aR}} - \frac{1}{e_{NR}}) \qquad \text{Btu/yr}$$

with

$$e_{NR} = \begin{array}{ll} 1.0 & \text{electric water heater} \\ .7 & \text{gas or oil water heater} \end{array}$$

where e_{aR} is the measured recovery efficiency from the mechanical system test data and e_{NR} is the recovery efficiency of a new water heater.

REDUCE WATER HEATER THERMOSTAT SETTING (150-130°F)

Electric Water Heater	365 kWh/yr
Gas Water Heater	36.5 therm/yr
Oil Water Heater	25.5 gal/yr

(NBS Measurements) (Ref. 20)

SHOWER FLOW RESISTORS

Assuming 10 showers of 5 minutes each per week and an equal mixing of hot and cold water, a flow resistor would lead to a savings of 1300 gal of hot water per year for each 1 gal/min reduction in flow rate of the shower head. Therefore, the hot water savings would be

$$1300 \ (F-2.5) \ \text{gallons of hot water per year}$$

where F is the measured flow rate of the existing shower head. This would lead to an energy savings of

$$7.55 \ (F-2.5) \times 10^5 / e_n \quad \text{Btu per year}$$

Where e_n is the recovery efficiency of the water heater. Using a recovery efficiency of 1.0 for electric water heaters and 0.7 for gas and oil water heaters one would predict an energy savings of

221 (F-2.5) kWh per year for electric water heaters
10.8 (F-2.5) therms per year for gas heaters and
7.70 (F-2.5) gallons of oil per year for oil water heaters.

TIMERS ON ELECTRIC WATER HEATERS

It has been shown that timers on electric water heaters can lead to a savings of approximately 5 kWh per day. Therefore the annual savings would be 1875 kWh per year for a typical household.

APPENDIX D

FIRST COST PRICING ASSUMPTIONS

Since the construction specifications for providing the weatheriza-
tion options are not part of this appendix, assumptions used in making
cost estimates for all options are stated as follows.

All cost estimates for the weatherization options are primarily
collected from the local community action groups or local contractors
recommended by the community action group and supplemented by construc-
tion suppliers catalogues, department store catalogues and the 1977
Means Building Construction Cost Data guide. Each local community
action group will identify whether the weatherization options will be
carried out by the labor forces in the local community itself or
furnished and installed by a local building contractor. In general it
is assumed that infiltration options are installed by local community
action groups and that all other options are installed by a local
building contractor.

1.   All estimates shown are "in-place" prices which include labor,
     material and overhead, and profit (where contracted out).

2.   Each estimate shown is the unit price for one option only.
     There will be some price reduction of the estimate for a large
     quantity purchase.

3.   Estimates are used for selecting energy conservation options only.
     The estimates are only of the order of magnitude. Actual installa-
     tion prices will have to be collected and tabulated during the
     demonstration phase of the weatherization project.

4.   Estimates are shown in dollar per square foot or linear foot for
     each item. These unit prices can be easily compared to the
     benefit side of energy conservation since the reductions of energy
     use are also expressed in the same units.

The assumptions for estimating each weatherization option are
listed as follows, since technical specifications for each of the
weatherization options are not yet available.

1.   Replace broken glass in windows: $/ft^2
     Remove broken glass and old glazing, cut new plate glass to fit
     existing opening and install glass. It is assumed that 24" x 24"
     size of glass would be the most common stock size from which the
     replacement pane is to be cut.

2. Reset glazing in windows: $/ft
    Apply glazing compound on outside and inside of existing window
    panes to make them weatherproof. A window size of 3 ft. by 5 ft.
    is assumed.

3. Install storm windows: $/ft^2
    Furnish and install a triple track storm window of up to 15 square
    feet in size. Screen is included. No special preparation on
    existing surfaces to receive the storm window is required.

4. Provide triple glazing for windows: $/ft^2
    Install a new storm window 3 ft. by 5 ft. size inside the existing
    window and storm window.

5. Install low emissivity films: $/ft^2
    "Lockspraygold" or equivalent: apply to the entire glass area
    of the window.

6. Weatherstrip windows: $/ft
    Use any weatherstripping material which is available in local
    hardware and specialty stores.

7. Caulk windows: $/ft
    Use suitable sealant or caulking compound for exterior weather-
    proof caulking.

8. Install insulating lining over existing window drapes: $/ft^2
    Use "Roclon" insulated drapery lining ($1.80 per yard of 48"
    width).

9. Install insulating shutters over windows: $/ft^2
    Install on the interior side of the window to reduce heat losses.
    Composed of 1-1/2" thick insulation sandwiched between 1/4" thick
    plywood, with R value = 7. Price includes hinges, trim, and
    finish painting.

10. Install storm door: $/ft^2
    Furnish and install a storm door of approximately 3' x 7' in size.

11. Install 2nd wood door: $/ft^2
    Install a standard grade exterior wood door. Installation will
    be either on the inside or outside of the existing door depending
    on the direction of swing of the existing door.

12. Replace exterior door with insulating door: $/ft^2
    Furnish and install a commercially available insulating door.
    It shall have a minimum of rating of R6.

13. Weatherstrip exterior door: $/ft
   Use any door weatherstripping material which is available in local
   hardware and specialty stores.

14. Caulk exterior door: $/ft
   Use suitable sealant or exterior weatherproof caulking.

15. Install new threshold: $/ft
   Furnish and install a new threshold that is compatible with the
   exterior door.

16A. Install insulation below grade of a first floor slab: $/ft^2
   Excavate, attach 2" styrofoam with adhesive to the edge of slab
   and footing. Make the exposed surface fireproof. Backfill to
   existing grade. 18" to 20" deep insulation is estimated.

16B. Install interior wall insulation for basement walls: $/ft^2
   Fur out from basement wall. Install 2" styrofoam. Install 3/8"
   thick drywall. Taping and painting are not included.

17A. Install interior wall insulation over solid masonry wall: $/ft^2
   Provide furring, install 2" thick styrofoam or 3-1/2" fiberglass
   insulation. Install dry wall. Provide wood base. Tape and paint
   walls with damp-proof paint.

17B. Install exterior wall insulation over solid masonry wall: $/ft^2
   Install "Drive-it" over exterior wall.

17C. Provide insulation (R-11) in existing wood framed walls: $/ft^2
   Fill frame walls with loose fill or other insulation by inserting
   an applicator through the interior side of the wall. Plug and
   paint with two coats of vapor barrier paint.

17D. Provide insulation (R-11) in existing veneer wall: $/ft^2
   Similar to assumption for 17C.

18. Insulate attic: $/ft^2
   Furnish and install loose fill or blanket insulation to satisfy
   R11, R30, R38 values. Install attic vents where needed.

19. Provide floor insulation: $/ft^2
   Provide blanket insulation to satisfy R19 and R30 values.

20. Weatherstrip attic hatch: $/ft
   Furnish and install locally available weatherstripping to make
   the attic hatch weather-tight.

21A. Seal up structural cracks on masonry walls: $/ft^2
   Provide "tuck-pointing" for a square foot area.

21B. Seal up structural cracks on wood siding walls: $/ft^2
Replace with similar siding and paint to match for a square
foot area.

21C. Seal up structural cracks on veneer wall: $/ft^2
Provide "tuck-pointing" for a square foot area.

22. Carpet floor: $/ft^2
Provide floor carpet.

23. Close-off unused portion of house:
Seal and tape existing interior doors.

24. Provide wind barrier around crawl space or basement wall:
Design specifically for an individual situation.

ASHRAE TYPE CALCULATIONS FOR ARCHITECTURAL OPTIONS (REF. 6)
(See Notes, below, for meanings of symbols used.)

INFILTRATION

Replace Broken Glass
$Btu/ft^2 \cdot yr$ = [0.018 x DD_a x 24 hrs] x [30 ft^3/hr + (22 ft^3/hr x DD_a/Htg. Days)]

Reset Glazing
$Btu/ft \cdot yr$ = [0.018 x DD_a x 24 hrs] x [.1 AC x 12000 ft^3/344 (1in) ft]

Replace Threshold
$Btu/ft^2 \cdot yr$ = [0.018 x DD_a x 24 hrs] x [300 ft^3/hr + (22 ft^3/hr x DD_a/Htg. Days)]

Seal Structural Crack
$Btu/ft^2 \cdot yr$ = [0.018 DD_a x 24 hrs] x [300 ft^3/hr + (22 ft^3/hr x DD_a/Htg. Days)]

Weatherstrip Windows
$Btu/ft \cdot yr$ = [0.018 x DD_a x 24 hrs] x [0.1 AC x 12000 ft^3/344 1f]

Caulk Windows
$Btu/ft \cdot yr$ = [0.018 x DD_a x 24 hrs] x [0.1 AC x 12000 ft^3/344 1f]

Weatherstrip Doors
$Btu/ft \cdot yr$ = [0.018 x DD_a x 24 hrs] x [0.1 AC x 12000 ft^3/344 1f]

Caulk Door
$Btu/ft \cdot yr$ = [0.018 x DD_a x 24 hrs] x [0.1 AC x 12000 ft^3/344 1f]

Weatherstrip Attic Hatch
$Btu/ft \cdot yr$ = [0.018 x DD_a x 24 hrs] x [0.1 AC x 12000 ft^3/344 1f]

*NOTES (including assumptions):

DD_a = degree days at balance point of house
.018 = .24 Btu (specific heat) x .075 lbs/ft^3 (density)
30 ft^3/hr = infiltration due to pressure difference with rag in
            opening
(22 ft^3/hr x DD_a/htg. days) = infiltration due to temperature
                                difference
300 ft^3 = infiltration due to pressure difference without blocking
            opening
12000 ft^3 = volume of building
344 (1in) ft = perimeter of doors and window sashes
AC = number of airchanges per hour

WINDOWS

Stage 1

Window Uninsulated (R = .88, U = 1.13)
$Btu/ft^2 \cdot yr$ = 1.13 x DD_a x 24 hrs

Storm Window (R = 1.79, U = .56)
$Btu/ft^2 \cdot yr$ = .56 x DD_a x 24 hrs

Managed Insulating Drape (R = 1.25 U = .80)
$Btu/ft^2 \cdot yr$ Night = .80 x DD_c* x 24 hrs
$Btu/ft^2 \cdot yr$ Day = 1.13 x DD_d* x 24 hrs
$Btu/ft^2 \cdot yr$ Total = Day + Night

Managed Shutter (R = 7.8 including glass, U = .13)
$Btu/ft^2 \cdot yr$ = .13 x DD_c x 24 hrs
$Btu/ft^2 \cdot yr$ Day = 1.13 x DD_d x 24 hrs
$Btu/ft^2 \cdot yr$ Total = Day + Night

Low Emmissivity Film (R = 1.33, U = .75 including glass)
$Btu/ft^2 \cdot yr$ = .74 x DD_a x 24

Stage 2

Storm Window and Drape (R = 2.07, U = .48)
$Btu/ft^2 \cdot yr$ Night = .48 x DD_c x 24
$Btu/ft^2 \cdot yr$ Day = .56 x DD_d x 24
$Btu/ft^2 \cdot yr$ Total = Day + Night

Storm Window and Shutters (R = 8.62, U = .12)
$Btu/ft^2 \cdot yr$ Night = .12 x DD_c x 24
$Btu/ft^2 \cdot yr$ Day = .56 x DD_d x 24
$Btu/ft^2 \cdot yr$ Total = Day + Night

Storm Window and Film (R = 2.63, U = .38)
$Btu/ft^2 \cdot yr$ = .38 x DD_a x 24

Triple Glazing (R = 2.78, U = .36)
$Btu/ft^2 \cdot yr$ = .36 x DD_a x 24

Stage 3

Triple Glazing and Drapes (R = 3.15, U = .32)
$Btu/ft^2 \cdot yr$ Night = .32 x DD_c x 24
$Btu/ft^2 \cdot yr$ Day = .36 x DD_d x 24
$Btu/ft^2 \cdot yr$ Total = Day + Night

*NOTES:
    DD_c = Degree Days during night at balance point of house
    DD_d = Degree Days during day at balance point of house.

Triple Glazing and Shutters (R = 9.7, U = .10)
$Btu/ft^2 \cdot yr$ Night = .10 x DD_c x 24
$Btu/ft^2 \cdot yr$ Day = .36 x DD_d x 24
$Btu/ft^2 \cdot yr$ Total = Day + Night

Triple Glazing and Film (R = 3.58, U = .28)
$Btu/ft^2 \cdot yr$ = .28 x DD_a x 24

DOORS

Existing 1-3/4" Solid Door (R = 2.18, U = .457)
$Btu/ft^2 \cdot yr$ = .457 x DD_a x 24

Storm Door (R = 3.23, U = .31)
$Btu/ft^2 \cdot yr$ = .31 x DD_a x 24

Existing Door + Wood Door (R = 5.04, U = .20)
$Btu/ft^2 \cdot yr$ = .20 x DD_a x 24

Insulating Door (R = 6, U = .17)
$BTU/ft^2 \cdot yr$ = .17 x DD_a x 24

ATTIC INSULATION

Component	R-Value
Outside surface	0.17
Asphalt shingles	0.44
3/4" wood	0.94
2 x 8 (rafters) at 16" o.c.	0.93
Air space	0.98
2 x 8 (joists) at 16" o.c.	0.93
1/2" plaster	0.32
Inside surface	0.61

Attic Uninsulated (R = 5.3, U = 0.19)
$Btu/ft^2 \cdot yr$ = 0.19 x DD_a x 24

Attic with R11 insulation (R = 15.3, U = .065)
$Btu/ft^2 \cdot yr$ = .065 x DD_a x 24

Attic with R19 insulation (R = 22.59, U = .044)
$Btu/ft^2 \cdot yr$ = .044 x DD_a x 24

Attic with R30 insulation (R = 32.6, U = .031)
$Btu/ft^2 \cdot yr$ = .031 x DD_a x 24

Attic R38 insulation (R = 40, U = .025)
$Btu/ft^2 \cdot yr$ = .025 x DD_a x 24

WALL INSULATION

Masonry Wall Uninsulated (R = 2.56, U = .39)
$Btu/ft^2 \cdot yr$ = .39 x DD_a x 24

Masonry Wall with R11 insulation (R = 12.6, U = .080)
$Btu/ft^2 \cdot yr$ = .080 x DD_a x 24

Frame Wall Uninsulated (R = 4.55, U = .22)
$Btu/ft^2 \cdot yr$ = .22 x DD_a x 24

Frame Wall R11 (R = 14.6, U = .069)
$BTU/ft^2 \cdot yr$ = .069 x DD_a x 24

MASONRY VENEER WALL

Component	R-Value
Outside surface	0.17
4" brick	0.80
Air space	0.97
1/2" plaster	0.32
Inside surface	0.68

Veneer Wall Uninsulated (R = 3.03, U = 0.33)
$Btu/ft^2 \cdot yr$ = 0.33 x DD_2 x 24

Veneer Wall R11 (R = 13, U = .077)
$BTU/ft^2 \cdot yr$ = .077 x DD_a x 24

BASEMENT WALLS

These values have been developed based on the analysis and formula
prescribed in Reference 21.

Basement Wall Insulated

Location	R-Value
Above grade	R=1.28, U=0.78

$Btu/ft^2 \cdot yr$ = 0.78 x DD_b* x 24

2 feet below grade   R=4.99, U=0.20
$Btu/ft^2 \cdot yr$ = 0.20 x DD_b x 24

*NOTES:
DD_b = Degree Days based on average temperature of basement.
(See table.)

4 feet below grade   R=6.98, U=0.14
$Btu/ft^2 \cdot yr$ = 0.14 x DD_b x 24

6 feet below grade   R=8.77, U=0.11
$Btu/ft^2 \cdot yr = 0.11 \times DD_b \times 24$

Basement Wall Uninsulated

R7 above grade   R=8.28, U=0.121
$Btu/ft^2 \cdot yr = 0.121 \times DD_b \times 24$

R7, 2 feet below grade   R=11.98, U=0.083
$Btu/ft^2 \cdot yr = 0.083 \times DD_b \times 24$

R7, 4 feet below grade   R=13.98, U=0.071
$Btu/ft^2 \cdot yr = 0.071 \times DD_b \times 24$

R7, 6 feet below grade   R=15.77, U=0.063
$Btu/ft^2 \cdot yr = 0.63 \times DD_b \times 24$

ASSUMED AVERAGE BASEMENT TEMPERATURE
DURING THE HEATING SEASON

Albuquerque, N.M.	57
Atlanta, Ga.	62
Charleston, S.C.	65
Chicago, Ill.	50
Colorado Springs, Colo.	49
Easton, Pa.	51
Fargo, N.D.	41
Los Angeles, Calif.	61
Miami, Fla.	76*
Minneapolis, Minn.	46
New Orleans, La.	69*
Oakland Calif.	56
Portland, Ma.	44
St. Louis, Mo.	56
Tacoma, Wash.	57
Washington, D.C.	56

* Where average basement temperature is over 65°F, DD_b is
  calculated using a base temperature of 65°F.

APPENDIX F

BUILDING MEASUREMENTS FOR THERMAL ANALYSIS

HOUSE NUMBER _____

DATE _____

Draw a plan on a separate sheet of paper

for each floor, basement, and attic

with dimensions on the outside of walls

and height from floor to ceiling in the

center of each plan. Give compass

orientation of house and convert

all inches to feet.

SINGLE GLAZED WINDOWS

1.	Height_____ft.,	Width_____ft.,	Area_____sq. ft.	Orientation_____
2.	Height_____ft.,	Width_____ft.,	Area_____sq. ft.	Orientation_____
3.	Height_____ft.,	Width_____ft.,	Area_____sq. ft.	Orientation_____
4.	Height_____ft.,	Width_____ft.,	Area_____sq. ft.	Orientation_____
5.	Height_____ft.,	Width_____ft.,	Area_____sq. ft.	Orientation_____
6.	Height_____ft.,	Width_____ft.,	Area_____sq. ft.	Orientation_____
7.	Height_____ft.,	Width_____ft.,	Area_____sq. ft.	Orientation_____
8.	Height_____ft.,	Width_____ft.,	Area_____sq. ft.	Orientation_____
9.	Height_____ft.,	Width_____ft.,	Area_____sq. ft.	Orientation_____
10.	Height_____ft.,	Width_____ft.,	Area_____sq. ft.	Orientation_____
11.	Height_____ft.,	Width ·_____ft.,	Area_____sq. ft.	Orientation_____
12.	Height_____ft.,	Width_____ft.,	Area_____sq. ft.	Orientation_____
13.	Height_____ft.,	Width_____ft.,	Area_____sq. ft.	Orientation_____
14.	Height_____ft.,	Width_____ft.,	Area_____sq. ft.	Orientation_____
15.	Height_____ft.,	Width_____ft.,	Area_____sq. ft.	Orientation_____
16.	Height_____ft.,	Width_____ft.,	Area_____sq. ft.	Orientation_____
17.	Height_____ft.,	Width_____ft.,	Area_____sq. ft.	Orientation_____
18.	Height_____ft.,	Width_____ft.,	Area_____sq. ft.	Orientation_____
19.	Height_____ft.,	Width_____ft.,	Area_____sq. ft.	Orientation_____
20.	Height_____ft.,	Width_____ft.,	Area_____sq. ft.	Orientation_____

STORM WINDOWS

1. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
2. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
3. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
4. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
5. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
6. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
7. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
8. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
9. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
10. Height_____ft., Width_____ft., Area . _____sq. ft. Orientation_____
11. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
12. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
13. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
14. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
15. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
16. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
17. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
18. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
19. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
20. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____

WOOD DOORS

1. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
2. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
3. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
4. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
5. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____

GLASS DOORS

1. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
2. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
3. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
4. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
5. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____

STORM DOORS + WOOD DOOR

1. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
2. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
3. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
4. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
5. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____

STORM DOOR + GLASS DOOR

1. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
2. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
3. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
4. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____
5. Height_____ft., Width_____ft., Area_____sq. ft. Orientation_____

BROKEN GLASS & STRUCTURAL CRACKS

Area of broken glass and large holes in exterior walls or roof

_____sq. ft.

ATTIC VENT

Area of attic vent

_____sq. ft.

WEATHERSTRIPPING

Number of weatherstripped doors_____
Number of unweatherstripped doors_____
Number of weatherstripped windows_____
Number of unweatherstripped windows_____

U-VALUE

Type on a separate page a list of materials and their thickness,
layer by layer from inside to outside for the following:

- Basement walls below grade
- Basement walls above grade
- Basement floor
- Each exterior building walls
- First floor
- Attic floor
- Roof

APPLIANCES

Number of refrigerators _____

Number of clothes washers _____

Number of clothes dryers _____

Number of dishwashers _____

Number of freezers _____

Number of television sets _____

Number of window air conditioners _____

Number of stoves _____

Number of ovens _____

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☐ Document describes a computer program; SF-185, FIPS Software Summary, is attached.

16. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.)*

This report comprises the plan of a research and demonstration effort to determine the fraction of energy that may be saved by installing weatherization retrofits in poor peoples' homes throughout the United States. Two broad groups of weatherization retrofits are considered for application in each dwelling: 1) "architectural," those affecting the building shell; and 2) "mechanical," those affecting space heating and service hot water systems. The optimum combination of weatherization options is defined as that set of retrofits which maximizes net savings (the difference between savings in fuel usage and the cost of the retrofits) over 20 years for a particular house and climatic environment. The retrofits will be selected through present-value benefit/cost analysis. The savings will be established through analysis of utility billings and fuel delivery records before and after weatherization. The report presents the background of the demonstration, the research tasks associated with the demonstration, a description of the diagnostic tests to be used, the rationale for economic decisions, the tests for evaluating mechanical systems, and the calculation methods used in selecting architectural options.

17. KEY WORDS *(six to twelve entries; alphabetical order; capitalize only the first letter of the first key word unless a proper name; separated by semicolons)* Community Services Administration; heating balance point analysis; low-income residences; marginal cost/benefit analysis in weatherization; optimum weatherization retrofit combinations; thermal analysis of residences.

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